Exterior Wall Construction in High-Rise Buildings

Masonry Cavity Walls and Veneers on Frame Buildings

Price: $6.00

Aussi disponible en français

This publication was prepared by W.G. Plewes, P.Eng., Ottawa, Ontario. Graphics by M.J. Coakeley, CMHC, National Office Support Centre.

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This project was funded by CMHC, but the views expressed are the personal opinions of the author and no responsibility for them should be attributed to the Corporation.

ISBN 0-660-10990-5
Cat. No. NH18-2/7-1E
Printed in Canada

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PREFACE

This book was written at the request of CMHC field office personnel who, over the years, have received many complaints from building owners about the failure of the exterior walls and windows of high-rise buildings to perform as intended. Too frequently major expenditures have been required to rectify problems, amounting in some instances to millions of dollars for the repair or replacement of facades; law suits have even been brought.

From a review of plans for buildings across Canada, it was apparent that most cases of faulty in-service performance could have been prevented by more careful design, construction, supervision and inspection. This publication tries to provide a limited explanation and illustration of some of the potential problems with masonry cavity walls and veneers on high-rise buildings which have structural frames. Other forms of masonry walls, such as solid masonry panel walls and bearing walls, are not dealt with, although many of the principles set forth here apply to other types of wall as well.

The discussions are necessarily brief and a list of readily obtainable references is provided for further enquiry.

It is hoped that a wide range of professionals might benefit from studying this advisory document, including architects, engineers, constructors, plans examiners and inspectors.

The publication was prepared for Canada Mortgage and Housing Corporation with the assistance of an advisory committe composed of: K.N. Burn, Division of Building Research, National Research Council, Ottawa, Ontario; E. Burnett, Technical Research Division, CMHC, Ottawa, Ontario; P. Meleta, Corporation of the Borough of Scarborough, Ontario; C.J. Perrault, PCL Construction, Edmonton, Alberta; J.W. Sawers, Technical Research Division, CMHC, Ottawa, Project Manager.

CHAPTER 1. INTRODUCTION

1.1 Topic and Purpose

The wall constructions discussed in this publication are masonry cavity and veneered walls on high-rise residential buildings which have steel or reinforced concrete structural frames. Such walls have certain advantages which have made them more popular in recent years:

(a) rain water penetrating the facing wythe of the wall drains into a cavity and can be conducted back to the exterior by suitable flashings and openings

(b) in some instances, insulation may be placed conveniently in the cavity rather than at the interior of the wall.

Well-built cavity and veneer walls have usually performed well. Unfortunately, in recent years faults in design or construction have too frequently led to poor servicing and expensive repairs. These errors are largely due to lack of observance of design principles and good construction practices.

Rain leakage is the commonest problem, but not the only one. Condensation within walls of moisture from the interior also occurs, as does spalling of bricks and buckling of panels due to moisture and thermally produced dimensional changes (Figs. 1 to 3). Such incidents have been reported in a number of countries besides Canada.

This publication is not a manual on masonry construction. Its purpose is to point out specific contributing causes of serviceability failures in high-rise buildings. To help avert such problems in the future, wall design principles are discussed and illustrated. The drawings are not fully developed designs, particularly in the matters of sizes and selection of materials, but are schematic, to facilitate discussion of the factors affecting performance.

Building science is an extensive technology today, but to keep the text within manageable limits, complicated explanations are avoided as much as possible. Where appropriate, reference is made to other publications and to the design and construction items covered by requirements of the National Building Code of Canada, Residential Standards and CSA Standards. A list of relevant codes and standards is given in Appendix A (p. 70).

Fig. 1 Efflorescence pattern from air leakage and internal condensation

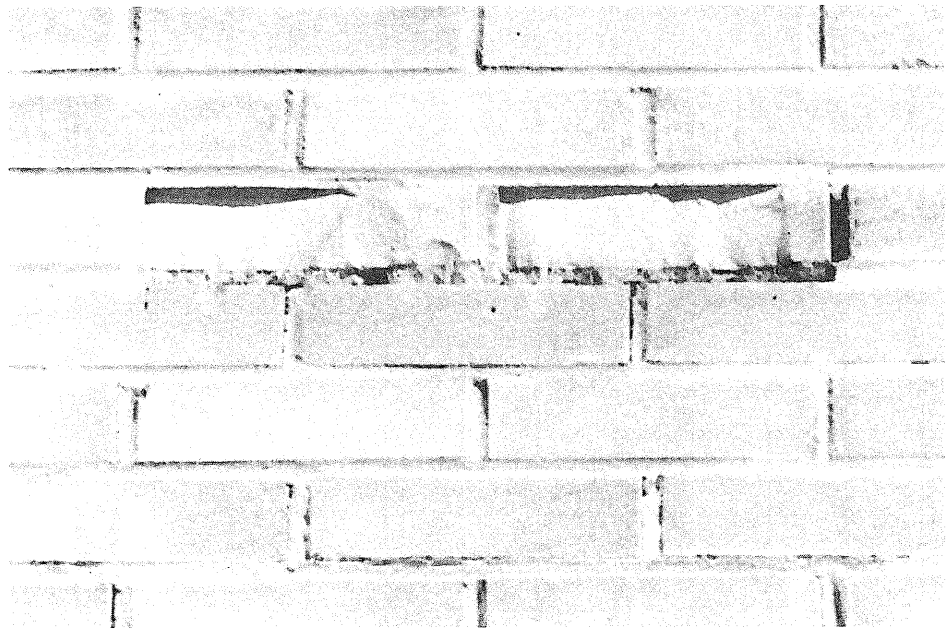


Fig. 2 Spalling of bricks from pinching at shelf angle due to frame shortening and brick expansion

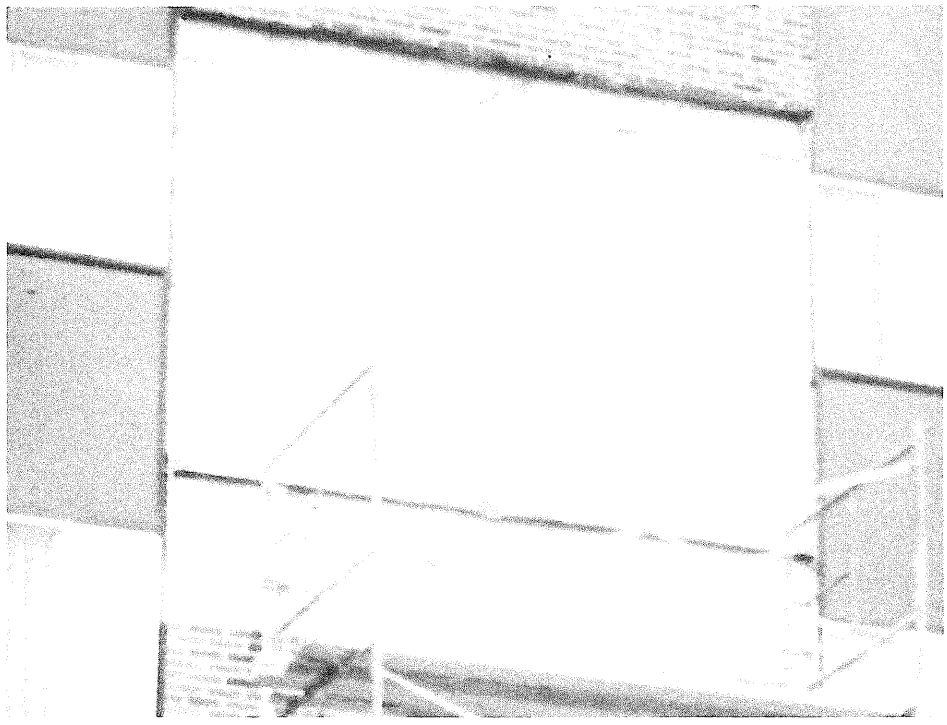


Fig. 3 Buckled panel due to frame shortening and brick expansion

CHAPTER 2. SPECIAL ASPECTS OF HIGH-RISE BUILDINGS

2.1 Definition

By regulation of the National Building Code of Canada (Ref. 1), buildings over three storeys in building height must be designed and built under the provisions of Parts 1 to 8 of the NBC rather than Part 9, or according to the provisions of Residential Standards (Ref. 2), except for a few Sections of Residential Standards that are applicable to all residential buildings (R.S. Section 1A(1)). In this document, therefore, high-rise buildings are taken to mean those of four storeys or more.

2.2 Practical Differences Between High- and Low-Rise Buildings

Although many aspects of the design and construction of high- and low-rise buildings are the same, certain features of high-rise buildings are more demanding and require closer attention:

- because of their height, high-rise buildings are more exposed to the elements, such as driving rain
- pressure differences across walls increase with the height of the building and cause greater air leakage
- because of their size, close inspection of highrises both during and after construction is more difficult
- large portions of the building are less readily accessible, making repairs more difficult and expensive
- there is a greater repetition of detail, so that failure of a component design item or construction procedure may occur many times, necessitating expensive remedial repairs
- expansions and contractions due to moisture and thermal changes in a vertical direction are magnified
- there are often greater lateral movements in the structural frame.

CHAPTER 3. CAVITY WALLS AND VENEERS

3.1 General

Cavity walls and veneered walls* both consist of a brick or other unit masonry facing, which is separated from an inner wythe or a back-up wall by an unfilled vertical space. The walls are often difficult to distinguish externally. Nevertheless, their differences should be understood, since they have different requirements for structural design, type of ties, and tie spacings.

3.2 Cavity Walls

The oldest form of cavity wall consisted of two masonry wythes separated by a 50 to 75 mm space and connected by masonry header units spanning the cavity. Metal ties are now preferred to headers because they do not provide as much of a thermal and water bridge and yet they permit small differential movements between the wythes (Fig. 4).

In cavity wall design, vertical and lateral loads are considered to be carried jointly by the facing and inner wythes. This depends on the ties having at least the size, strength and stiffness of those specified by CSA Standard S304-M78, *Masonry Design and Construction for Buildings* (Ref. 3). Cavity wall ties are 5 mm diameter** Z-, rectangular individual wire ties, or the continuous "ladder" or truss type made of wire having "equivalent strength, stiffness, bond, and corrosion resistance" (S304, Clause 3.7.2). Thinner ties, corrugated sheet metal strip ties, or adjustable ties do not qualify as cavity wall ties.

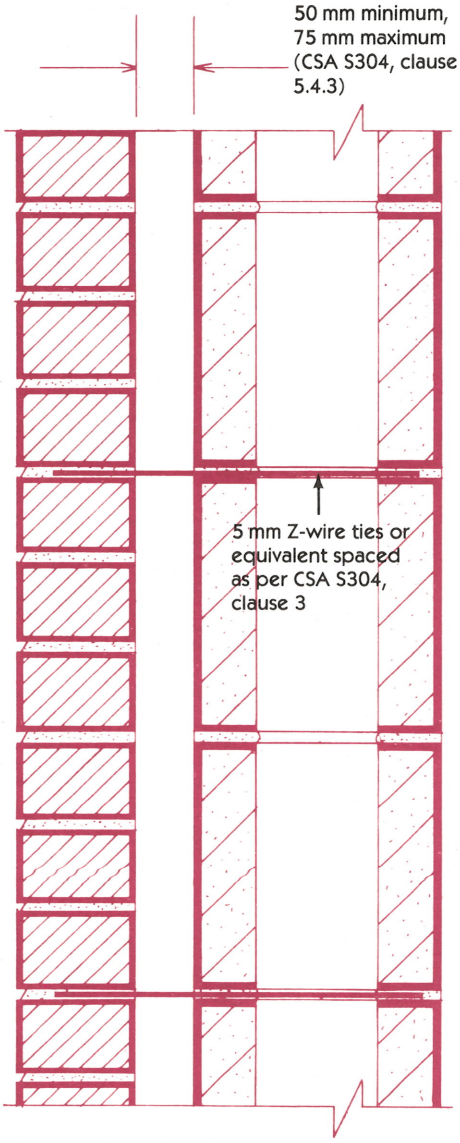


Fig. 4 Cavity wall

*The term veneer here refers to unit masonry facing (CSA S304, Clause 2.1) of brick, block, or a similar size stone. Large slabs of stone and thin facings of glass, tile or stone are also called veneers but are not discussed in this publication. (See Clauses 6.3 to 6.6.)

**Hard conversion of 4.76 mm, corresponding to the 3/16-ins. diameter ties formerly used.

The size and spacing of ties required by CSA S304 are structurally adequate for cavities up to 75 mm in width, which is the maximum allowed under Clause 5.4.3. A minimum cavity width of 50 mm is also specified to maintain an effective barrier to water. Walls with cavities smaller than 50 mm can be built under Clause 3.7.3.3, but these are considered simply as solid walls with unfilled collar joints and do not qualify as true cavity walls, even though they satisfy cavity wall structural and tie requirements.

On concrete and steel-framed buildings, the inner wythes of cavity panel walls are usually supported by the edge of the floor slab, with the outer wythe carried on steel shelf angles (Figs. 5-7).

Alternatively, in exposed slab construction, both the exterior and interior wythes are supported on the floor slab: that is, the slab penetrates both wythes of the wall and is exposed on the exterior of the building (Fig. 8).

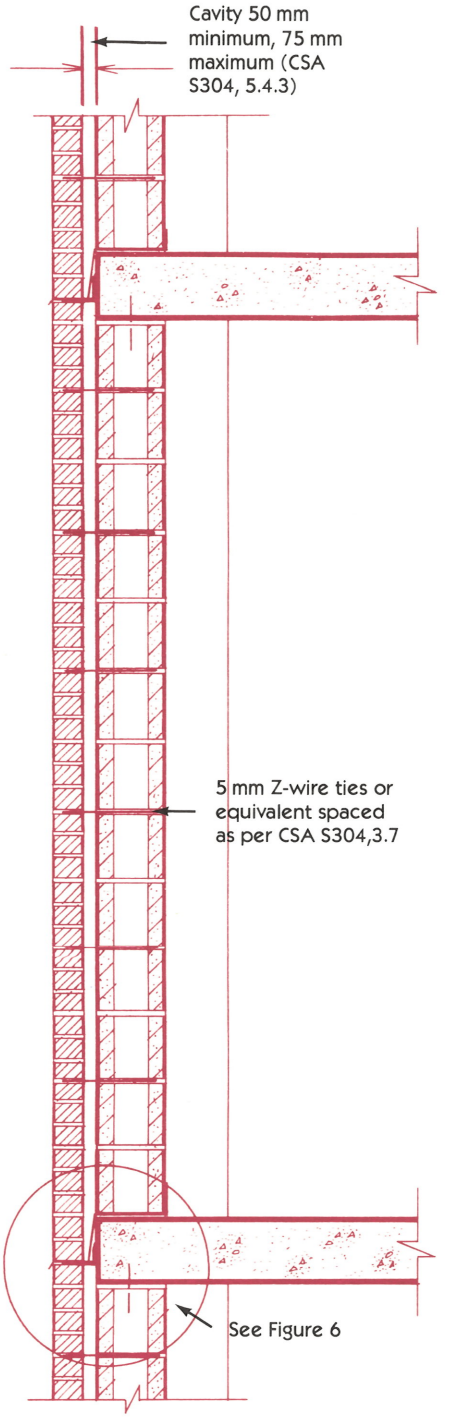


Fig. 5 Brick and concrete block cavity wall on concrete frame (insulation, air barrier, vapour barrier, and finish not shown)

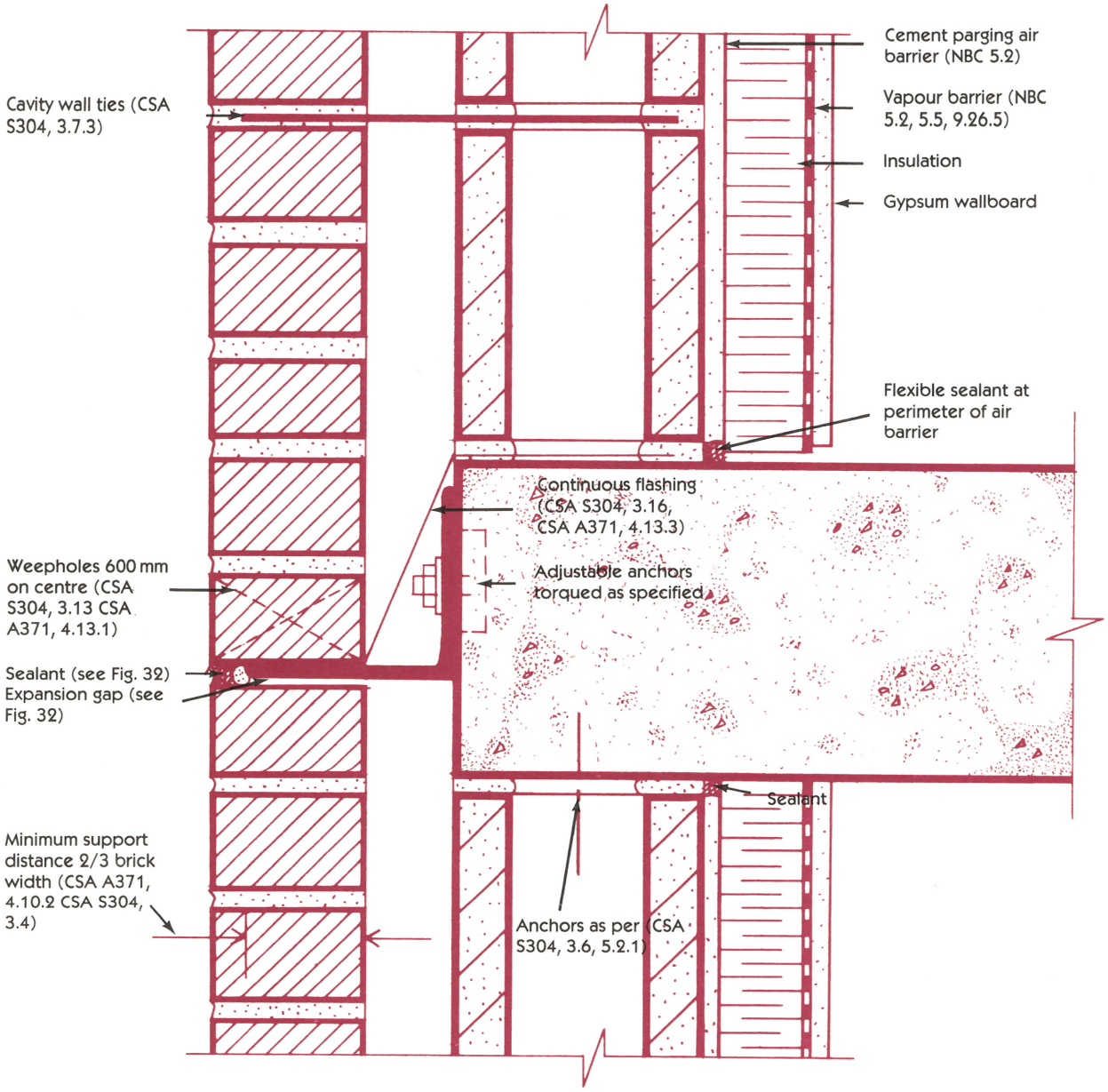

Cavity wall ties (CSA S304, 3.7.3)
Cement parging air barrier (NBC 5.2)
Vapour barrier (NBC 5.2, 5.5, 9.26.5)
Insulation
Gypsum wallboard
Flexible sealant at perimeter of air barrier
Continuous flashing (CSA S304, 3.16, CSA A371, 4.13.3)
Adjustable anchors torqued as specified
Weepholes 600 mm on centre (CSA S304, 3.13 CSA A371, 4.13.1)
Sealant (see Fig. 32)
Expansion gap (see Fig. 32)
Sealant
Minimum support distance 2/3 brick width (CSA A371, 4.10.2 CSA S304, 3.4)
Anchors as per (CSA S304, 3.6, 5.2.1)

Fig. 6 Brick and concrete block cavity wall on concrete frame (detail at slab)

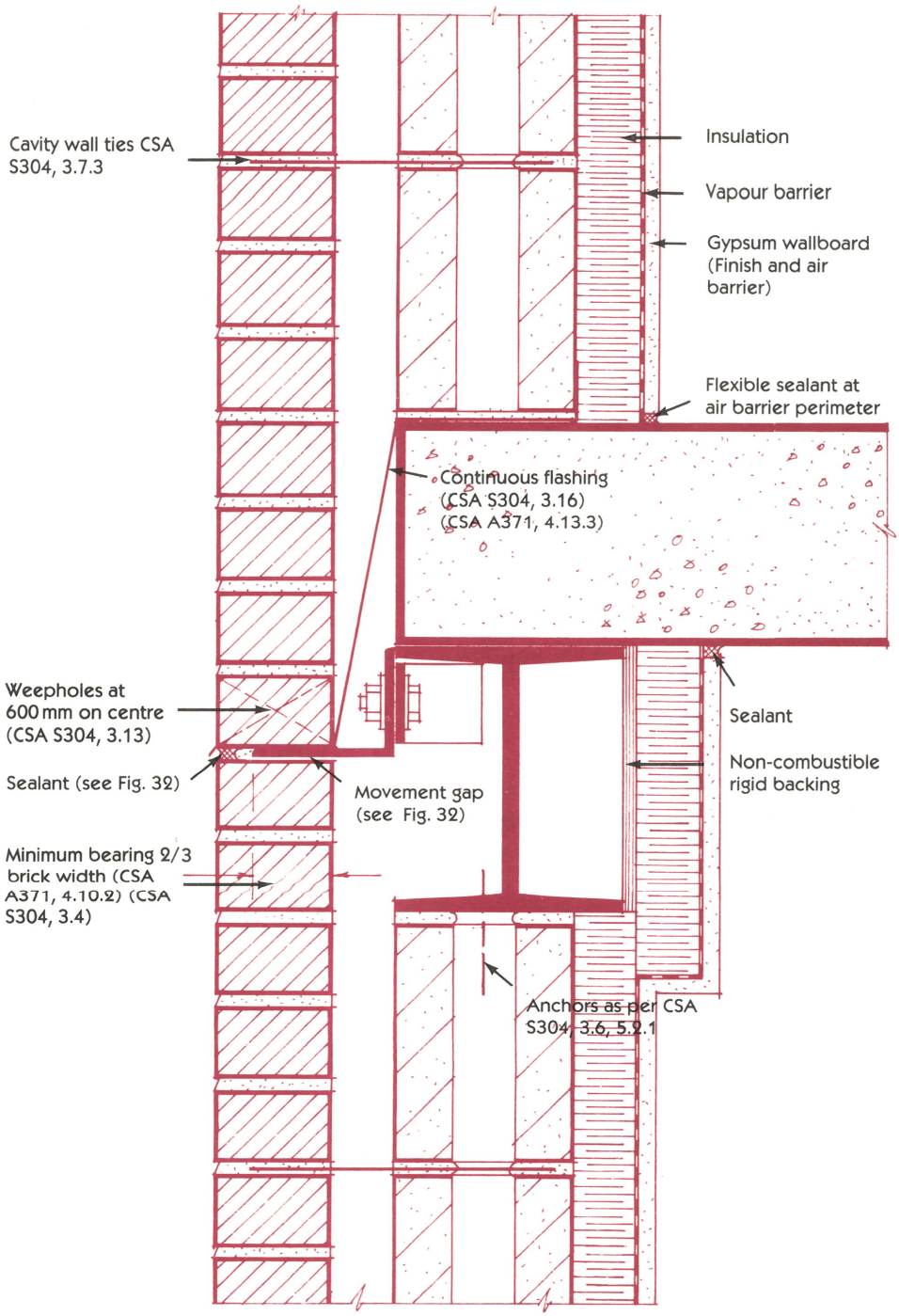

Cavity wall ties CSA S304, 3.7.3
Insulation
Vapour barrier
Gypsum wallboard (Finish and air barrier)
Flexible sealant at air barrier perimeter
Continuous flashing (CSA S304, 3.16) (CSA A371, 4.13.3)
Weepholes at 600 mm on centre (CSA S304, 3.13)
Sealant
Non-combustible rigid backing
Sealant (see Fig. 32)
Movement gap (see Fig. 32)
Minimum bearing 2/3 brick width (CSA A371, 4.10.2) (CSA S304, 3.4)
Anchors as per CSA S304, 3.6, 5.2.1

Fig. 7 Brick and concrete block cavity wall on steel frame (detail at steel spandrel, beam and slab)

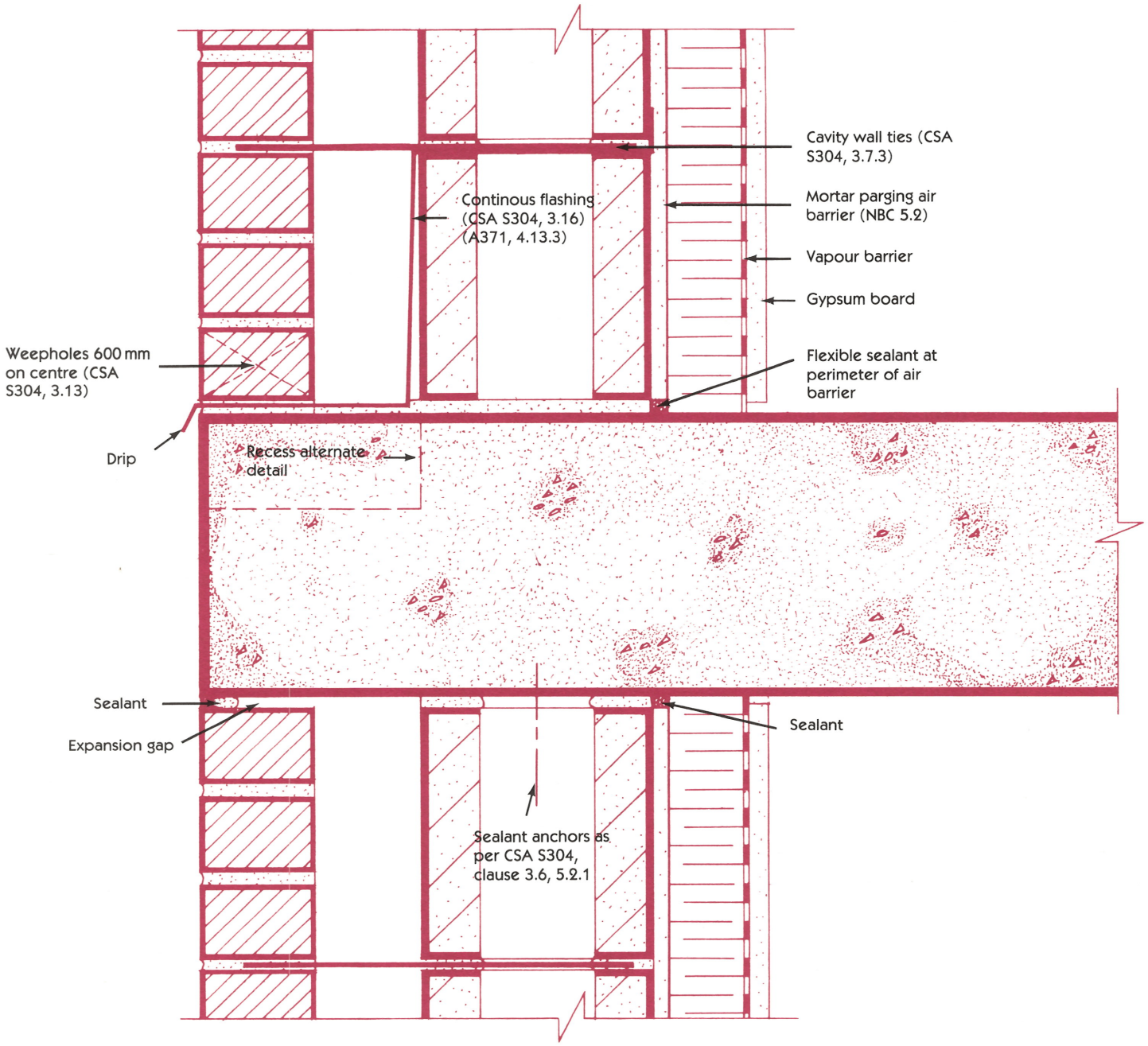

Cavity wall ties (CSA S304, 3.7.3)
Continous flashing (CSA S304, 3.16) (A371, 4.13.3)
Mortar parging air barrier (NBC 5.2)
Vapour barrier
Gypsum board
Weepholes 600 mm on centre (CSA S304, 3.13)
Flexible sealant at perimeter of air barrier
Drip
Recess alternate detail
Sealant
Expansion gap
Sealant
Sealant anchors as per CSA S304, clause 3.6, 5.2.1

Fig. 8 Brick and concrete block cavity wall on through the wall slab (detail at slab)

3.3 Veneered Walls

A unit masonry veneer consists of a facing wythe of brick, concrete blocks, or stone attached to an inner supporting wall, which may be another masonry wythe, a concrete wall, or steel studs. The facing wythe has to carry its own weight but otherwise is not considered to contribute to the vertical or lateral load resistance of the wall (CSA S304, Clauses 2 and 6.1.1). In veneered panel walls on structural frames, in particular, there are no significant external vertical design loads on the wall, but the inner masonry wythe or other type of backup is designed to resist the wind or other lateral loads. Generally there is a drainage gap between the veneer and the backup wall, and any forces on the facing are transmitted across the gap to the backup by ties.

Where the gap is 25 mm or less, galvanized, corrugated sheet steel strip ties are permitted (Fig. 9) (CSA S304, Clause 6.2.6). One end is embedded in a mortar joint of the inner wythe or, where the backup is not masonry, fastened to it by some method of adequate strength. The other end of the strip is embedded in a mortar joint of the veneer. CSA S304 calls for not less than 28-gauge strip ties, 25 mm wide. However, such thin ties have little buckling resistance to loads, and in high-rise construction it is advisable to use at least 22-gauge (0.76 mm) ties. The length of strip ties is determined by the thickness of the veneer and the method of tying to the supporting wall.

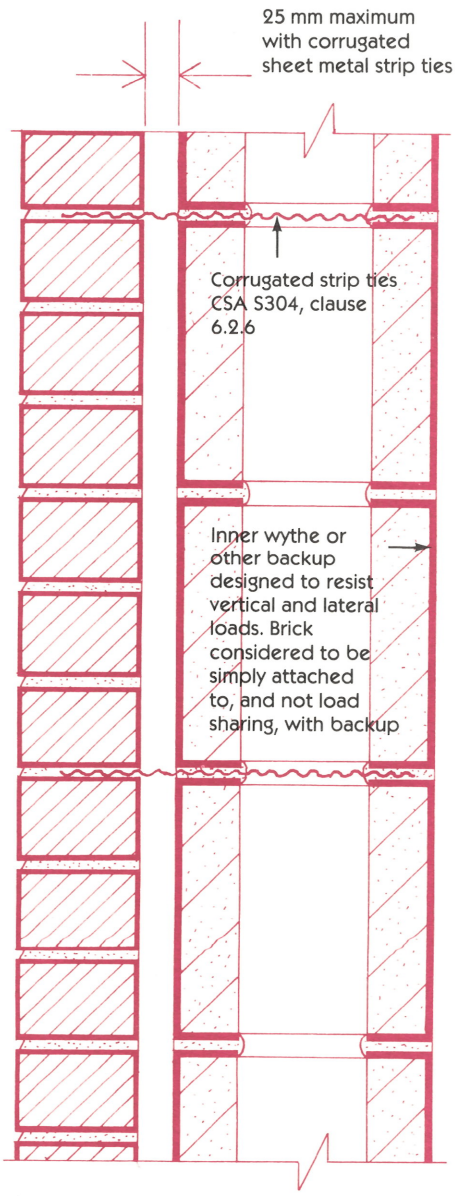

25 mm maximum with corrugated sheet metal strip ties
Corrugated strip ties CSA S304, clause 6.2.6
Inner wythe or other backup designed to resist vertical and lateral loads. Brick considered to be simply attached to, and not load sharing, with backup

Fig. 9 Brick veneer

Unit masonry veneers may be constructed with a gap between the facing and the backup greater than 25 mm, but in this case stronger and stiffer ties must be used (CSA A371, 4.7.2.4). Continuous ladder or truss type ties with 3.65 mm (9 gauge) cross-wires are frequently employed and have the advantage of ensuring regular horizontal 400 mm spacing of ties (cross-wires). The longitudinal wires also offer a degree of crack control. Some patented veneer ties have vertical adjustment features, but their strength and stiffness is generally unknown. Designers should bear this in mind; special tests may be necessary to determine the structural adequacy of patented veneer ties. Where the veneer is attached to a concrete wall or passes in front of a beam or column, "dovetail" ties are commonly used. These are a standard adjustable tie, 2.67 mm (16-gauge) or greater in thickness and 25 mm wide. One end is wedge-shaped to fit into a similarly shaped slot embedded in the concrete. The other end is bent up or corrugated to anchor it into a mortar joint of the facing wythe.

The weight of a veneer wythe is carried by the structural frame in a manner similar to the outer wythe of a cavity wall, but in this case support is required at vertical intervals no greater than 3.6 m (CSA S304, Clause 6.2.3), which practically means at each floor level.

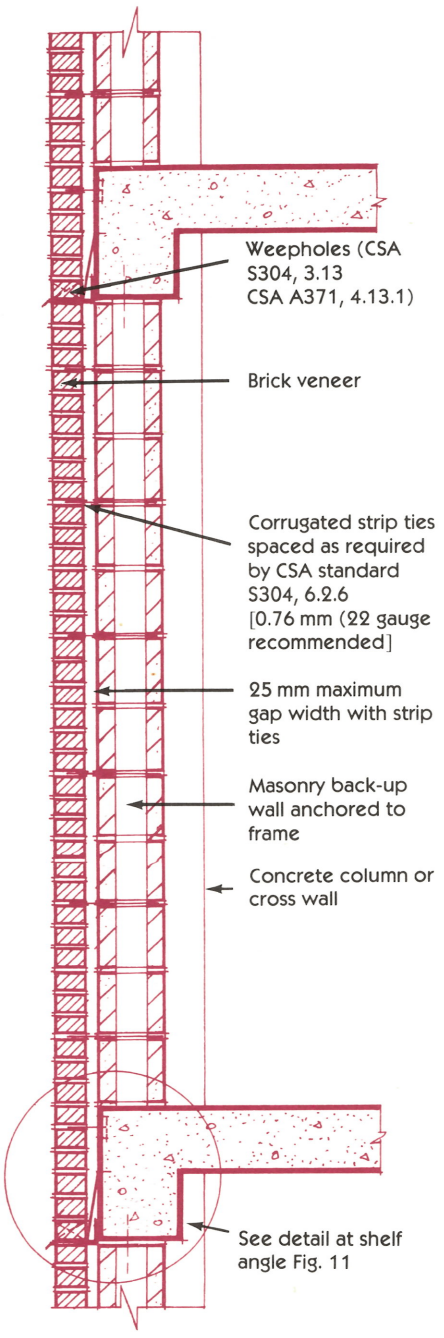

Weepholes (CSA S304, 3.13 CSA A371, 4.13.1)
Brick veneer
Corrugated strip ties spaced as required by CSA standard S304, 6.2.6 [0.76 mm (22 gauge recommended]
25 mm maximum gap width with strip ties
Masonry back-up wall anchored to frame
Concrete column or cross wall
See detail at shelf angle Fig. 11

Fig. 10 Brick veneer with corrugated strip ties to concrete block back-up wall (insulation, air barrier, vapour barrier and finish not shown)

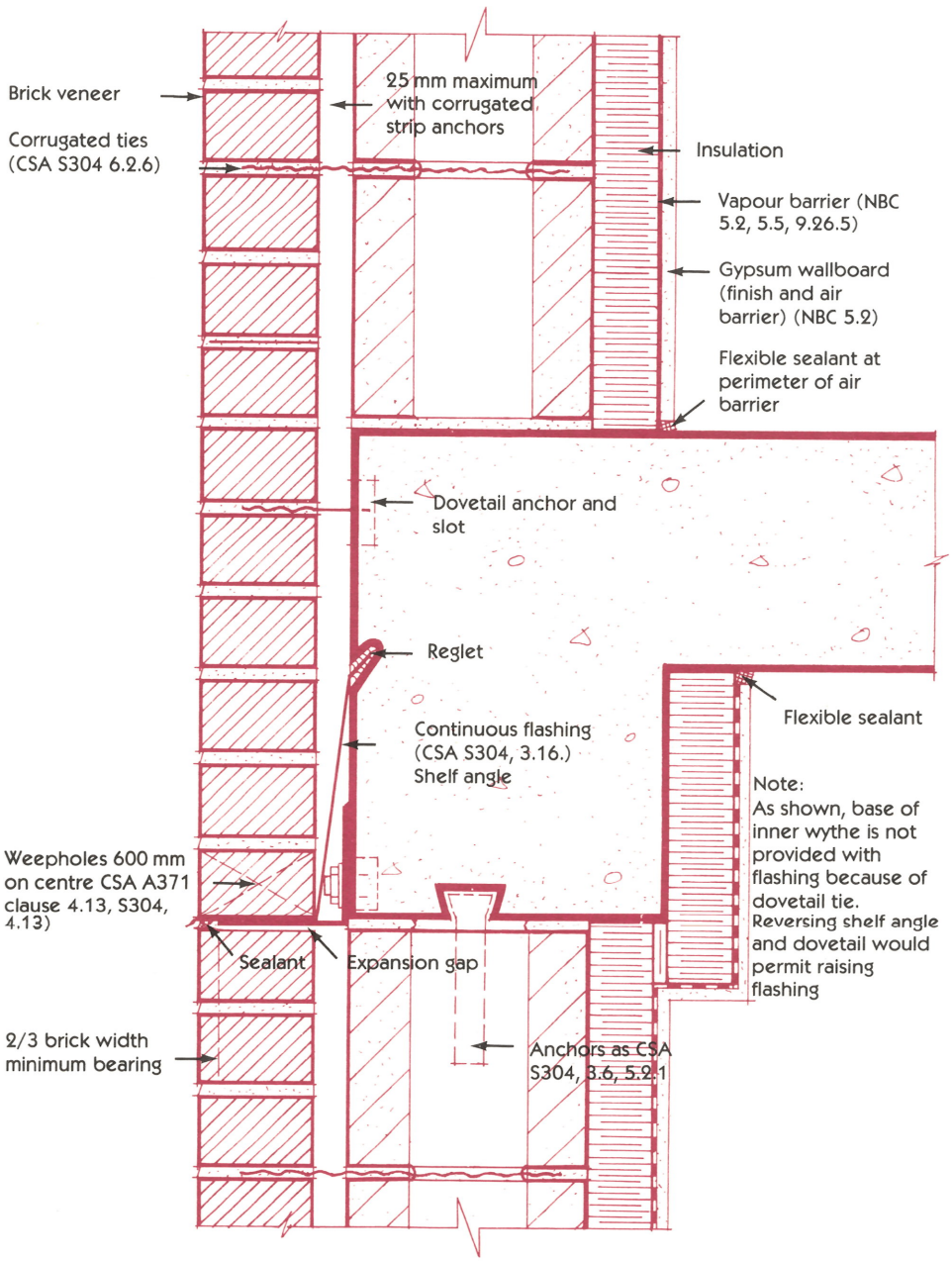


Fig. 11 Brick veneer on concrete block backup and concrete frame (detail at spandrel beam)

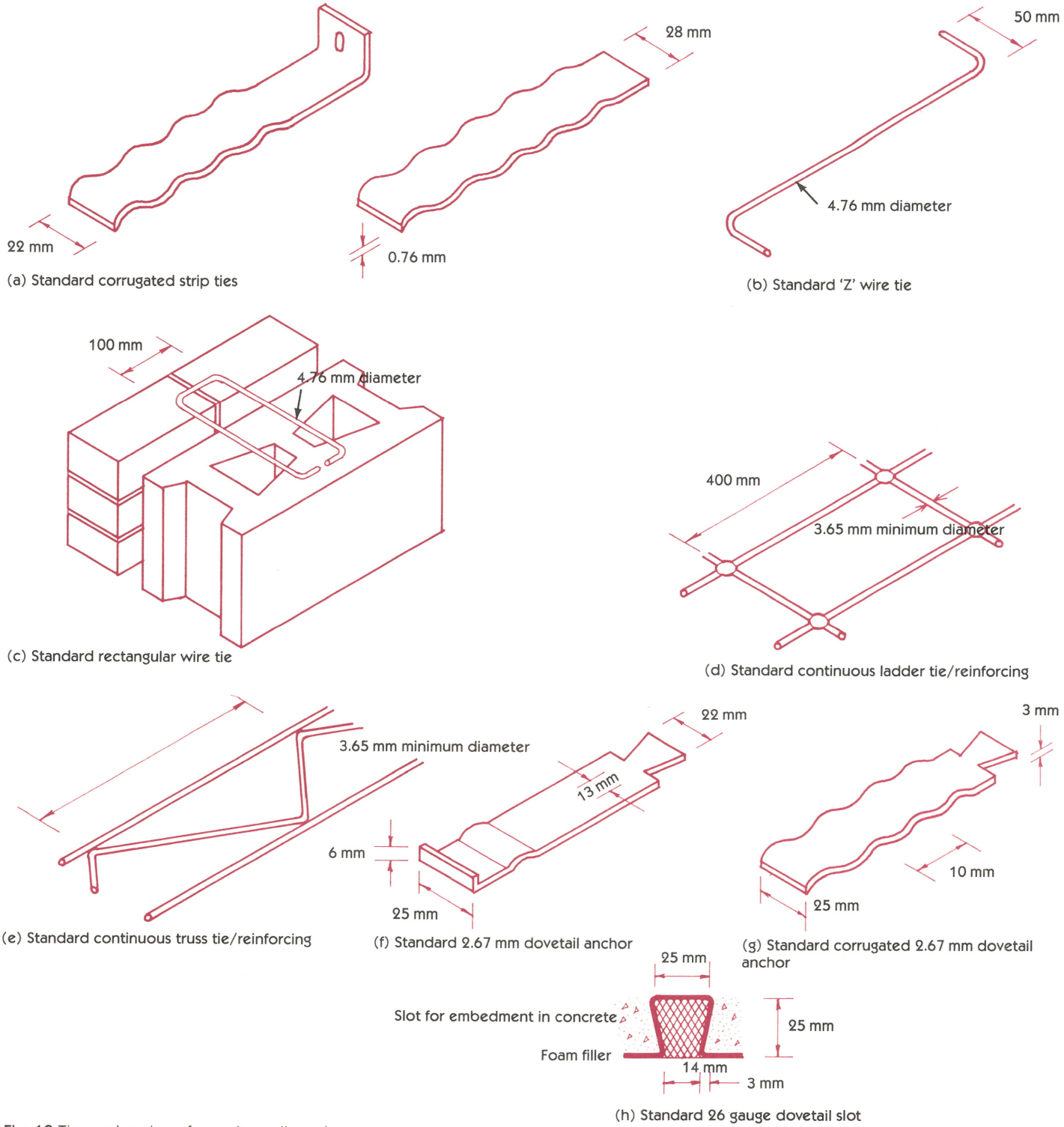
3.4 Discussion of Ties

There is at present no special CSA standard for masonry ties, but those referred to above and illustrated in Fig. 12 are more or less standard. From long usage, and some laboratory testing, they are known to have adequate strength and stiffness when properly installed at the spacings stipulated in CSA S304. That standard also calls for ties to be corrosion-resistant and for steel ties to be galvanized to one of the specifications stated in Clause 3.3.3.1, corresponding to the size and shape of the tie material. CSA A371-M1980, *Masonry Construction for Buildings*, states requirements for the installation of ties (Clauses 4.6.3, 4.6.4).

A number of cases have been found where corrugated sheet metal strip ties were rusted through completely within a few years. In all cases it was clear that 28-gauge ties were too thin and that the zinc galvanizing was a minimal wipe coat. Thicker 22-gauge (0.76 mm) ties should be used, with at least 427 g/m^2 (sum of both sides) hot process zinc galvanizing.

Corrugated strip ties have sometimes been used to connect brick veneer to metal stud backup walls. The unsupported length of strip ties between the brickwork and the backup should not exceed 25 mm because of their low compressive buckling strength. If the outside sheathing is a soft material, the inner end of the ties should be attached directly to the studs. Special patented ties have been developed to better connect the brick veneer to the steel studs, but their use should be based on evidence of appropriate strength and stiffness, or should be verified by test. In some current uses, ties are screwed directly to the stud through gypsum board exterior sheathing, which is reasonably hard when dry but rapidly softens when it gets wet, giving an unstable connection for ties. Therefore precautions should be taken in design and construction to ensure that gypsum board is protected from all sources of moisture, including rain and air leakage, and vapour diffusion. Workmanship must also be good: a screw that misses the stud, or a screw with too fine a thread or spun in the hole by overdriving, would result in a very low strength connection. BIA *Technical Note on Brick Construction 28B* (revised), February 1980, states that when brick veneer is used over metal studs in buildings more than three storeys in height, a good deal of "care and attention is necessary for satisfactory performance".

A CSA standard for masonry ties is under preparation, which will cover more completely size, configuration, material, strength and corrosion reistance. Such a standard should help to improve tie design and eliminate problems. It may also provide a basis for code revisions on size and spacing, allowing wider cavities to accommodate greater amounts of wall insulation, which is the current trend.



(a) Standard corrugated strip ties

(b) Standard 'Z' wire tie

(c) Standard rectangular wire tie

(d) Standard continuous ladder tie/reinforcing

(e) Standard continuous truss tie/reinforcing

(f) Standard 2.67 mm dovetail anchor

(g) Standard corrugated 2.67 mm dovetail anchor

(h) Standard 26 gauge dovetail slot

Fig. 12 Ties and anchors for cavity walls and veneers

CHAPTER 4. MECHANISMS

4.1 General

Before discussing further the causes and prevention of problems with cavity walls and veneers, it will be helpful to review the mechanisms of rain penetration, thermal resistance, moisture exfiltration and building movements that affect building performance and need to be considered in wall design. Exhaustive technical discussions of these are not attempted here, but it is necessary to know the essential facts.

4.2 Rain Penetration of Masonry

Since high-rise buildings are periodically subjected to driving rains, designers should ensure that wall claddings must not leak. The Division of Building Research of the National Research Council and other bodies have carried out extensive studies of the rain penetration of masonry; although the subject is complicated because of the variety of possible materials and designs, the principles are understood.

Rain may quickly wet exposed areas of the face of a masonry wall, but only during the most prolonged or frequent rains are the units and mortar likely to be completely saturated. Usually the materials themselves are too dense for water to pass through quickly. If water penetrates a wall, it is generally through fine capillary passages (actually unbonded areas) at the unit to mortar interface, through unfilled mortar joints, or through movement or shrinkage cracks. Raindrops that actually hit on a crack are not the main cause of leakage. Rather, water running down the wall face is drawn into the capillary passages at the joints and, if there is pressure due to wind, the water will flow through the wall. Water bridging larger cracks in the brickwork or holes in the mortar may also be carried into or through the wall by wind pressure and gravity.

Solid masonry can be reasonably watertight under a set of favourable conditions. The three most important are: *compatibility of units and mortar, filled mortar joints*, and *sufficient wall thickness*.

Compatibility of unit and mortar properties is a complex matter concerning a suitable match between the suction rate of the unit and the water retention of the mortar. However, it can be readily understood that if the unit absorbs water from the mortar too rapidly, or if the mortar is not plastic or wet enough, it may stiffen too rapidly, so that the units do not bed well and establish close contact with the mortar. This leaves unbonded areas, which account for the capillary cracks mentioned previously. Mortar materials and proportions are usually specified, but the mixing and consistency of the mortar are subject to conditions on the site. The wetness of the mix is adjusted by the mason to give the easiest workability, so that with the given materials the plasticity of the mortar is to a degree self-correcting. However, individual habits, such as laying mortar too far in advance of placing the units, may allow it to stiffen too rapidly. A complete discussion of compatibility is beyond the scope of this document; references 5-10 explain the subject in more detail.

In general, unless there is a special pre-job investigation, which usually is not the case, optimum compatibility may not be achieved, but adherence to CSA standards for material and construction gives the best assurance that the units and mortar are of good quality and have reasonable compatibility.

Obviously, solid masonry will not be watertight unless all the mortar joints are filled. These include the bed joints, the head joints, and, in multi-wythe solid walls, the joint between the wythes (the collar joint). Masonry where the head joints are only partially buttered with mortar, where the bed joint is too heavily furrowed with the point of the trowel before laying the units, or where the collar joint is left empty, is almost certain to leak. (Concrete blocks normally have only the face shells bedded in mortar, but where they are used as a back-up wythe or have some other protection, this has been found to be satisfactory.)

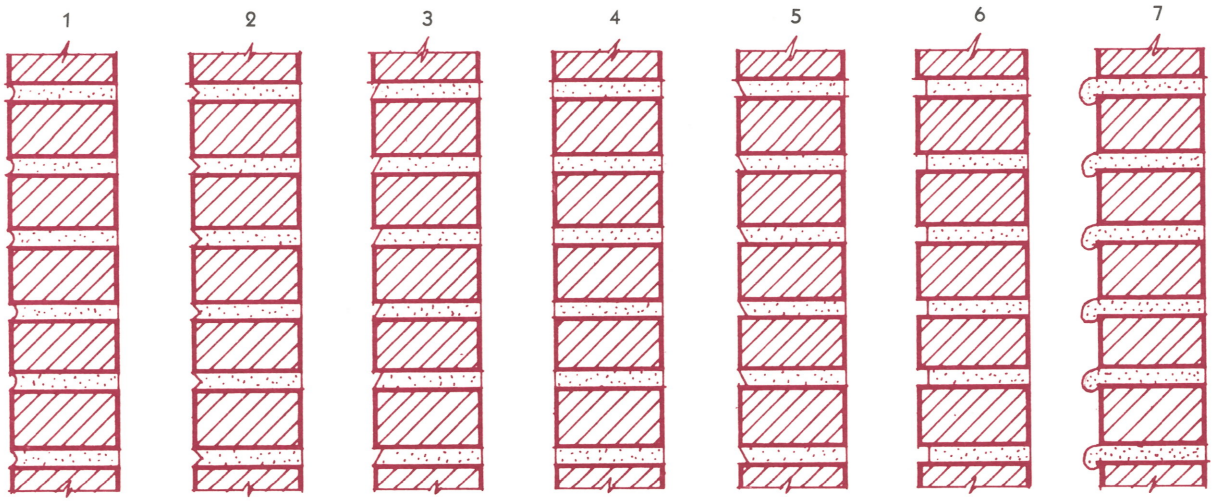
The thickness of the wall is an important factor. Older buildings are more watertight partly by having walls 300 mm or more thick. Rainwater entering the brickwork was stored and later evaporated. Yet even walls of these thicknesses could leak if they were not well constructed. Under only the most favourable conditions can 200 mm double- wythe solid masonry walls be counted upon to be sufficiently watertight. Parging the backs of walls with mortar greatly improves their rain resistance if their construction is otherwise good and the parging is uncracked.

Besides these three items of prime importance, tooling of the mortar affects masonry's rain resistance. Tooling face joints to a concave or V-shaped profile with a special tool compacts the mortar against the units and helps to close capillary cracks. This can reduce leakage considerably. Flush, raked, or extruded joints catch water running down the wall, are not compacted, and should not be used for rain-exposed conditions. Figure 13 illustrates the types of joints referred to above.

Any masonry can leak if copious quantities of water are flushed onto it because of poor design. Copings, ledges, sills and balconies should be designed to direct water away from the wall rather than flushing it onto the masonry. The provision of suitable projections, drips and flashings will be dealt with in more detail later.

Leak-proof solid walls are attainable, but there is a problem of ensuring satisfactory performance both because of the wide variety of materials available and also because of the miles of mortar joints which occur in any given building. Because of this, many designers of high-rise buildings have turned to using cavity or veneered walls that offer a second line of defence (Figs. 4-11). In this kind of construction, any water penetrating the outer wythe runs down its inside face within the cavity space. By providing flashings at shelf angles and ledges, this water can be diverted back to the outside of the wall through weepholes.

Where through-wall (exposed slab) construction is used (Fig. 8), there is a greater risk of leakage, since any defect in the flashing allows direct access of water to the interior through the base of the interior wythe.



1. Concave joint
2. V-joint
3. Weathered joint
4. Flush joint — not recommended for rain resistance.
5. Struck joint — not recommended for rain resistance
6. Raked joint — not recommended for rain resistance
7. Extruded — not recommended for rain resistance

Fig. 13 Types of mortar joint treatment

4.3 Thermal Resistance

For comfort, economy and energy conservation, building walls must have adequate heat insulation value. Given inside and outside ambient temperatures and thermal resistance values, it is possible to calculate the rate of heat flow through a wall and also the temperature at any point within it by the methods explained in Ref. 11. In general, the rate of flow is directly proportional to the temperature difference and inversely proportional to the heat resitance of the material; so that,

$$\text{Heat Loss} \propto \frac{\text{Temperature difference}}{\text{Thermal resistance (R)}} \times \text{time}$$

From this expression, it can be seen that the heat loss from a building depends on the duration of outside temperature below room temperature—conventionally expressed as the number of degree days per year below 18°C, which reflects the coldness of the local climate.* The normal design procedure is to ensure that walls have the thermal resistance (R-value) specified in standards corresponding to the number of degree days for the location (Ref. 12).

The overall R-value of a wall construction is simply the sum of the individual resistances of the various layers of materials in its thickness. Resistance (RSI) values for most common building materials in metric units are given in CMHC Builders' Bulletin No. 282 (Ref. 13). For some homogeneous materials, such as concrete, the tabled RSI values are for 1 mm thickness, and must be multiplied by the actual thickness of the material. For non-homogeneous materials, such as hollow blocks and some thin materials, the RSI values are quoted for the actual specific thicknesses (e.g. 0.125 m^2 C/W for 100 mm sand and gravel concrete blocks).

There is also a resistance to heat flow at wall surfaces due to the rather complex transfer of heat from air to solid material. For practical purposes, this is treated as the resistance of a layer of stagnant air; in CMHC Builders' Bulletin No. 282, RSI values are given for both inside surface films (still air) and outside surface films (moving air). Air spaces, such as cavities within walls, also have insulating value, and RSI values for these are listed as well.

With this information at hand, the total RSI value of a wall construction can be calculated. Taking the cross-section in Fig. 11 as an example, and assuming thicknesses for the materials,

Outside air film	0.030
100 mm brick veneer	0.074
25 mm air space	0.171
150 mm concrete block	0.160
50 mm foil covered urethane insulation 50 × 0.042	2.100
12 mm gypsum board 12 × 0.0062	0.074
Inside air film	0.120
Total RSI value	2.729 m^2°C/W

CMHC Builders' Bulletin No. 267 requires an RSI value of 2.0 m^2°C/W for all above-grade walls of buildings over three storeys in height. As can be seen from the above calculation, the insulation provides the major resistance to heat flow.

*Although normal room temperature is about 23°C, a base of 18°C is used to allow for body heat and electrical usage.

4.4 Vapour Resistance

At a given temperature, air can contain a maximum amount of moisture, at which point it is "saturated". Any excess moisture will condense into a mist or onto adjacent surfaces. The moisture content of saturated warm air is greater than that of saturated cold air since the higher the temperature, the more moisture air can hold.

The moisture condition of air is usually described, not by the weight of water in it, but by the amount contained as a percentage relative to saturation. This is its Relative Humidity (RH).**

Moisture can pass through building materials by diffusion of water molecules in vapour form. This requires a driving force, which comes from the pressure of the vapour as a gas. At a given temperature, the higher the RH, the higher the vapour pressure. Specifically, however, it is a difference in vapour pressure across a material that causes the vapour to flow from the high to the low pressure side.

In cold weather the actual weight of moisture in outdoor air is small, but its RH may be in the 75 or 90 percent range. Brought into a building, it is warmed and, if no moisture is added, its RH will drop, since at the higher temperature the air is further away from saturation. For example, air at freezing temperatures and 75 percent RH raised to 22°C will have a RH of only 15 to 20 percent.

**To be precise, Relative Humidity is defined as the ratio of the existing water vapour pressure to the vapour pressure at saturation at that temperature. Under normal building conditions, this is closely equal to the ratio of the weight of water in the air to the weight at saturation.

4.5 Air Leakage

In residential buildings, however, moisture is added to the air by laundry, cooking, bathing and other activities of the occupants. This added moisture has the effect of raising the indoor vapour pressure above that outside, and because of this pressure difference, moisture will tend to diffuse outwards through the walls. At the same time, in winter there is also a gradient of temperature across the walls, and if the diffusing vapour reaches a zone of lower temperature at which the extra moisture will saturate the air (called the dew-point), condensation can occur and cause dampness.

Different materials have different degrees of vapour resistance; calculation procedures are given in Ref. 11 by which the rate of diffusion through the various layers of a wall may be estimated, and also to predict if and where condensation will occur. For normal residential buildings, such calculations are not usually necessary. Instead, building standards require a layer of highly vapour-resistant material (that is, a vapour barrier) to be installed in the wall on or near the warm side of the insulation (NBC Clause 5.2.1). The latter provision is to ensure that the plane at which the moisture is stopped is at a temperature above the dew-point.

The ability of a material to resist the flow of vapour through it is related inversely to a measurable property called permeance; that is, the lower the permeance, the higher the vapour flow resistance.

In Imperial units, the measure of permeance is the "perm", which is defined as 1 grain of water per hour passing through 1 square foot of the material under a pressure equal to 1-inch of water (gr./hr/ft^2/in-H20) (1 grain = 1/7000 lb.). For some materials, this is quoted in tables as the vapour permeance per inch of thickness, in which case the property is called "permeability" and its measure the "perm-inch". This must be divided by the total thickness under consideration to obtain the permeance of the material.

The SI Unit of permeance is expressed as 1 nanogram of water passing through 1 square metre per Pascal of pressure (ng/s/m^2/Pa) (1 ng = 10^{-9} grams). The SI equivalent of the Imperial perm may be obtained by multiplying by 57.2. Permeability is given per mm of thickness.

Although vapour diffusion may easily be controlled by vapour barriers, air leakage through cracks and openings in the building envelope can convey many times as much moisture through walls (Ref. 14). In high-rise buildings, air leakage is accentuated by the inward and outward air pressure differences generated by differences in temperature and density between inside and outside air. This is usually called stack effect, and it increases with building height (Ref. 15).

In a building having uniform openings or leakage paths over its height, the pressure differences across walls vary theoretically, as is indicated in Fig. 14. Net outward pressures occur in the top half with a maximum at the top. Inward pressures pertain at the bottom with a plane of zero pressure difference near mid-height. During cold winter weather, the maximum pressure at the top and bottom would be in the 12-25 Pa range for a 5-storey building and over 100 Pa for a 20-storey building. Figure 14 is an oversimplification of practical conditions since the magnitude of pressures and their distribution can be considerably modified by the wind, mechanical ventilation systems, the tightness of floors, and the influence of elevator and other shafts (Refs. 11 and 16). Nevertheless, pressures in the order of those stated above have been measured on specific buildings. Also, at certain times of the year, clear evidence of the outward flow of air may be seen at the tops of many buildings by the patterns of efflorescence or dampness on the brickwork.

It is instructive to examine air leakage rates found in tests. The *ASHRAE Fundamentals Handbook - 1977* (Ref. 17) gives the air leakage rate of 215 mm plain brick masonry as 0.15 cfm per square foot under a differential pressure of 0.10-in. H20. At this rate, and assuming the air is at 30 per cent RH and 23°C, a gallon of water per square foot would be carried into or through such a wall in four winter months. Not all of the moisture would condense in the masonry, since only the excess over saturation at the dew-point could condense and some would be carried right through with the air, but it is clear that there is potential for considerable moisture in walls from this source.

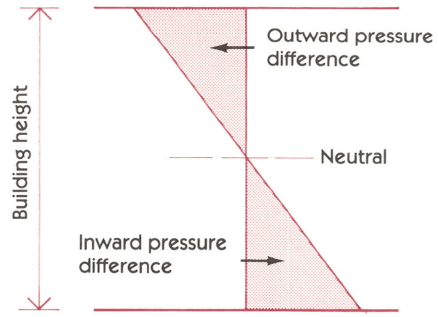


Fig. 14 Simplified representation of stack effect in building with uniformity distributed leakage paths in its height

Plastering or parging of masonry has been found to reduce air leakage in brick test panels by a factor of 100. However, in tests of actual buildings having various types of masonry panel walls plus insulation, vapour barrier and finish, about the same rates of air leakage (0.10 to 0.20 cfm per sq. ft.) were found with or without parging on the masonry (Ref. 18). (Similar rates of leakage were found with buildings having metal or precast concrete claddings.) It is evident, therefore, that air finds leakage paths around the inside finish at baseboard level, at the junctions of window frames and walls, above hung ceilings, and at fixtures. Parging on the masonry can also be bypassed at shrinkage cracks around its perimeter, through cracks in the parging itself, or around windows and service ducts penetrating the wall. Rather than air leaking uniformly through the building envelope, it is likely to be concentrated at the available leakage paths. This accords with the often observed patchiness of visible moisture in upper storeys near windows, at slab level, or where there is a concealed break in the inside barriers to air behind the facing.

Building materials and whole buildings are not the inert objects they seem. Changes in dimensions occur almost continuously and can lead to cracking or other deleterious effects. The causes of these movements are load strains, changes in moisture content, and temperature changes in the wall and structural frame materials.

Movements due to Load's Elastic Deformation

Any loaded material will shorten or lengthen depending on whether it is in compression or tension. When initially loaded, the deformation is nearly proportional to the load and is then known as elastic deformation. Concrete, with a strength of 20 MPa, for example, loaded in compression to a stress of 8 MPa, will shorten about 0.4 mm/m (0.04 per cent). Steel, being stiffer, would require ten times as much stress to give the same strain, but since it is normally stressed to a higher level, the deformation will be of about the same order.

Long-Term Deformation

Under a constant load, some materials undergo further deformation with time in addition to the initial elastic deformation. This additional deformation (called creep) is best described as a sort of plastic flow. Concrete is notable for this, and the creep movement can be 1.5 to 2 times the elastic deformation. Creep takes place at a decreasing rate and most of it will have occurred within two to three years. Steel does not creep significantly at working stress levels.

Moisture Movements

Most porous building materials will absorb moisture when in contact with water, or from the air, if the temperature of the material is below the condensation (dew) point corresponding to the relative humidity (degree of saturation) of the ambient air. Reversal of the conditions results in drying out. Concrete expands or contracts as its moisture content changes, but for reasons not gone into here, the net long-term effect is drying shrinkage in a normal air environment. Concrete block masonry may shrink 0.3 to 0.6 mm/m (0.03 to 0.06 per cent) depending upon the type of mortar, the age of the blocks when placed, how they were cured (low pressure steam or autoclave), how they were stored, and the block materials.

Clay bricks, on the other hand, have a net expansion as they come into hygric equilibrium with the air after firing, although the process is not well understood. This requires time, and the expansion that takes place in the wall depends partly on the age of the bricks when they were laid. The range of clay brick masonry expansion is not yet well defined for Canadian bricks, but 0.2 mm/m (0.02 per cent) is considered an average value.

Thermal Movements

It is well-known that materials expand or contract with changes in temperature. For both steel and concrete the change in dimension is about 0.55 mm/m (0.055 per cent) for a 50°C change in temperature. The equivalent value for concrete block masonry is a little less, about 0.045 per cent, and for dry brick masonry about 0.032 per cent.

General

The values of movements just quoted are intended to give an idea of their magnitude. An accurate calculation of building movement would require more detailed information. The changes in length may seem quite small but over long lengths there can be sizeable movements. For example, an unrestrained concrete block wall 30 m long would shorten about 12 mm because of shrinkage. Other movements are of the same order of magnitude. Under some circumstances they are additive, or they may be in opposite directions, partially cancelling out. (Moisture and temperature movements, for example, can be in the same or opposite direction.) In general, it is restrained or prevented movements or differential movements between connected elements that sometimes cause problems.

CHAPTER 5. WALL ELEMENTS

5.1 Purpose and Functional Components of a Wall

The purposes of an exterior wall are:

(a) to protect the occupants and contents of the building from rain, snow, wind or sun

(b) to permit economical control of the interior temperature and moisture conditions for comfort and use

(c) to provide security against intrusion.

We are concerned here with only the first two functions, which the wall should be able to perform without excessive deterioration and maintenance over the life of the building.

To be fully effective, a wall must have the following six basic elements.* While one element of the wall may serve more than one function, if any of these are omitted or are deficient, the wall will be liable to service failure.

1. A structural supporting system to resist lateral and vertical loads
2. A rain/snow/sun screen (exterior cladding)
3. A vapour barrier
4. An air barrier
5. A thermal barrier (insulation)
6. Movement control joints as necessary.

*A wall may also be required to be fire and sound resistant, but these are topics outside the scope of this document.

5.2 The Structural System

All buildings have load supporting systems. Wood stud walls of houses, for example, have their own strength. Some buildings, including highrises, have masonry-bearing walls which support the floors directly. However, most high-rise buildings have steel or reinforced concrete structural systems composed of columns, beams, cross-walls and slabs. The walls are supported by the frame (see Note below), which also provides the building's resistance to vertical floor loads and lateral loads such as winds and earthquakes.

The structural design of buildings, especially with regard to design loads and safety, is covered in Part 4, Design, of the National Building Code. Part 4 in turn refers to CSA standards for the detailed structural requirements for steel, reinforced concrete and masonry. To ensure that all structural requirements are met, the Code stipulates that the structural design be done by a professional engineer or architect (NBC Clause 4.1.1.2(2)).

Note: The cavity walls and veneers covered in this publication are generally supported by the frame at each floor level. Masonry walls filling the rectangular spaces between columns and floors are called *panel walls*. Where there are long runs of windows so that the masonry occurs only as horizontal bands beneath the sills, the term *spandrel wall* is sometimes used.

In some buildings the masonry rests only on the foundation and stands outside of a structural frame for the full height of the building. This is called a masonry *curtain wall*; it is not discussed here since such walls are uncommon in residential high-rise buildings.

5.3 Rain/Wind/Snow/Sun Screen

In the front line of a building against the effects of climate is the exterior cladding. This may be a skin of some impervious material arranged in overlapping shingle fashion. In other cases the elements of a cladding, such as precast concrete, may be butted side by side and the joint between them caulked or otherwise sealed to exclude rain and snow. The success of this depends on all the joints being tight and defect free — something which is difficult to achieve. An improvement on this may be an open joint system designed to equalize the air pressures across the cladding, thus eliminating the main force pushing water through the wall (the "Open Rain Screen Principle"). A complete general discussion of cladding design is found in Reference 11.

Masonry cavity and veneer walls are hybrid systems. The masonry itself consists of many small elements where the connecting joints are filled and sealed with mortar, which bonds the units together. Previous discussion indicated that its basic rain resistance depends on compatibility between units and mortar, filled joints, and thickness. Since the choice of material may be limited and the workmanship difficult to control to the necessary degree, there is always a chance that solid masonry may leak. With a cavity, however, a degree of air pressure equalization is achieved across the exterior facing wythe, which reduces the leakage tendency; in other words, it acts, at least partially, as an open rain screen. Moreover, water that does penetrate the outer wythe is stopped by the cavity and diverted outwards. The details of the system which require careful design and construction are the flashings, weepholes, copings and drips. Defects in these defeat the design objective.

5.4 Thermal Barrier (Insulation)

Although masonry panel walls are not assumed to contribute to the primary wind resistance of a building as a whole, they do receive the direct force of the wind, which must be transmitted to the structural frame. On the basis of tests and experience, the ties and tie spacings specified in codes and standards are expected to be adequate to transmit the forces from the facing wythe to the inner wythe or backup wall, which in turn must therefore be anchored to the frame (CSA S304, Clause 3.6).

Direct infiltration of a wall by snow is rare. Melted water from snow on sills, copings, ledges and balconies, however, can saturate parts of a wall if there are not effective slopes, projections and drips to direct it away from the wall. This can lead to wall leakage or freeze-thaw damage.

The sun does not directly affect masonry after the mortar is cured. However, by raising and lowering the temperature of masonry, thermal movements are produced which can cause problems if they are not provided for by the design (see Movement Joints). The sun also has a long-term effect on the weathering of most sealants.

The National Building Code and Residential Standards give the basic requirement that buildings for residential occupancy have "sufficient thermal insulation to prevent moisture condensation on the interior surfaces of walls, ceilings and floors during the winter months and to ensure comfortable conditions for the occupants" (NBC 9.26.2.1, RS26B(1)). The actual thickness of insulation is not prescribed, but CMHC Builders' Bulletin No. 332, 1981 (Ref. 12) states minimum values for the thermal resistance of walls and other building elements corresponding to the local number of degree days.

Since the thermal resistance of a wall assembly is the sum of the resistance of its various layers, where the insulation is located in the wall makes no theoretical difference. In cavity and veneer systems, therefore, the designer has the option of placing the insulation on the interior (room side) of the wall, or in the cavity space. However, each arrangement has its own technical and practical advantages.

Interior Insulation

Advantages:

(a) The insulation, vapour barrier and air barrier can be installed from the floors after the masonry work is finished and the building is closed in.

(b) The completeness of these items can be closely inspected and defects can be easily repaired.

Disadvantages:

(a) The whole of the exterior wall and the edge members of the structural frame are outside the insulation and subjected to the full range of outdoor thermal changes, with the associated dimensional changes and tendency for joints to open up in air and vapour seals.

(b) The insulation, vapour barriers and air barriers are not continuous over the building envelope but are interrupted by the floor slabs, beams, columns and partition walls, which require careful attention to their details and the sealing of joints.

(c) The edges of floor slabs are exposed to cold temperatures and form a heat bridge through the wall (See Thermal Bridges, page 59), creating a source of heat loss and internal condensation.

(d) Services are cut into the insulation and vapour barrier.

Insulation in Cavity

Advantages:

(a) Insulation may be applied over the whole of the inner wythe and frame, uninterrupted by cross-walls, floors and columns, so that a more uniform distribution of insulation obtains over the whole building.

(b) The frame and inner wythe are on the warm side of the insulation and are therefore in a relatively uniform temperature environment.

5.5 Vapour Barrier

(c) The thermal bridging of floor slabs is reduced or eliminated.

(d) Chases, electrical outlets, heating elements and ducts do not penetrate the insulation, air barriers and vapour barriers.

(e) Exposed masonry inside finish can be used if desired.

(f) With suitable details, window frames can be fastened to the inner wythe or the warm side of the insulation, which reduces thermal breakage problems; also there is less stress on caulking or membrane seals between window frames and walls.

(g) Provides a time-lag radiation potential from the mass of the material on the warm side of the insulation.

Disadvantages:
(a) Since the insulation and masonry go up together, it is difficult to inspect the work and repair defects once they are in place.

(b) The insulation must be worked around the ties.

(c) The details of flashings and insulation need to be carefully worked out to avoid mutual interference (Fig. 20), especially if the cavity is closed up because of a misalignment of the edges of the floor slabs.

(d) The insulation must be applied to the face of the inner wythe from a staging, and weather conditions may not always be right for good workmanship.

Wherever there are prolonged sub-zero winter conditions, as in most parts of Canada, *ASHRAE Fundamentals Handbook* (1977) recommends that every well-constructed modern dwelling have a vapour barrier.* It is also a requirement of the National Building Code (Section 5.2) and of Residential Standards (RS26E(1)).

For the normal relative humidity conditions in homes and offices in winter (10 to 50 per cent), a vapour barrier having a permeance of 45 ng/Pa·s·m^2 or less is considered to provide sufficient vapour protection. This has the vapour resistance of a Type II vapour barrier conforming to CAN2-51.33-M79, *Vapour Barrier: Sheet for Use in Above Grade Building Construction* (Ref. 19). The above-mentioned standards refer to sheet materials only (NBC 9.26.3.4)(RS26C(4)), but other materials, such as reinforced plastics, metal sheets, or impermeable mastics and coatings, which have equivalent vapour resistance, are also used where suitable. Two coats of oil-based paint on the inside finish of walls can be an effective vapour barrier (Ref. 14).

Certain lightweight, cellular, plastic-type insulations may serve also as the vapour barrier if their permeability is not greater than 6 ng/Pa·s·m. (NBC 9.26.5.2. RS26E(2)). For this use they should be high density, air impermeable materials that do not take up moisture; they should not expand and warp unduly under moist conditions. Other cellular plastic insulations may require additional vapour barrier protection.

Vapour barriers are intended to have the major resistance to water vapour in the wall so that the very small amount of moisture that does get through does not cause a damaging level of moisture in the other materials. It is also expected that the remainder of the wall construction outside the vapour barrier is comparatively permeable and in warm weather will dry out by capillary action and evaporation. Where a second, relatively vapour resistant, layer exists on the cold side of the insulation, any moisture penetrating the vapour barrier may become trapped and accumulate between the two layers. Such a situation should be avoided if possible and is not normally encountered in masonry walls; but it could occur if the outside wythe is of unusually dense stone or brick or if a glazed or painted brick is used. In such cases an internal vapour barrier of higher resistance should be installed. NBC Clause 9.26.3.4 (RS26C(4)) requires a Type I vapour barrier conforming to CAN2-51.33-M79, which has a maximum permeability of 15 ng/Pa·s·m^2.

Vapour barriers must be installed on the warm side of the wall, that is inside the insulation, and should be continuous over the whole wall, including studs and framing members. While the workmanship should be good, with proper laps and seals at joints according to the material used, and also free from accidental holes and damage, vapour barriers are not sensitive to minor defects, since the increase in diffused moisture is proportional to area. (The effect of a small hole will also be small.) This statement applies only to moisture diffusion and *if the vapour barrier is intended to act as the air barrier as well*, even a small hole can be critical.

*The term "vapour retarder" is coming into use instead of "vapour barrier".

5.6 Air Barrier

It is often assumed that a building with a good vapour barrier is fully protected against exfiltrating moisture without considering air leakage. As was stated in Chapter 4, even with an installed vapour barrier, vastly greater amounts of moisture can be carried into a wall by air leaking through accidental holes, around window frames, through cracks due to dimensional changes and even through materials such as masonry.

A vapour barrier may also serve as the air barrier, provided it is free from tears and gaps and is sealed at all edges and joints. Flexible barriers and membrane strips across cracks must also be supported by other rigid materials; otherwise the inward and outward air pressures through cracks will cause them to bulge and pull away from their laps and connections, creating holes for escaping air. In high-rise buildings it is often more convenient to ensure that the major barrier to air is a separate element. This may be parging on masonry, or alternatively the inside finish, such as plaster or wall board. To be fully effective, the designated air barrier must be sealed at the edges, around all penetrating ducts or fixtures, at potential shrinkage cracks between walls, columns and beams, and around window frames.

Effects of Air Leakage

In winter, moisture carried by leaking air condenses on the inner cold surfaces of masonry and accumulates as frost. In spring, it melts and migrates by capillary action to the outside wall surface, often bringing salts from the bricks and mortar with it. For extended periods at this time of the year parts of the wall may appear visibly damp and the evaporating moisture may have left efflorescence on the masonry. This is most frequently observed near leakage paths around window frames, at slab level, or wherever there is a concealed break in the air resistance of the interior wall. These visible signs of air leakage generally increase with height and are more pronounced in the upper storeys, where the highest outward pressure differences exist, and on the leeward side from the prevailing wind, where the wind suctions add to stack effects. Sometimes moisture or efflorescence is visible, mainly on the north side or other shaded areas where drying is the slowest (See 7.4, Efflorescence).

At present, it is difficult to state what limits should be put on air leakage and the extent of the measures that should be taken to prevent it. While some air infiltration and exfiltration may be required for ventilation, its rate is generally uncontrolled. It has been estimated (Ref. 20) that up to 50 per cent of the heating load of a building may be attributable to air leakage. Other investigations (Ref. 18) indicate, however, that it may be 10 per cent or less where mechanical air change systems can have an overriding effect on any heat loss due to stack effects and wind. Full ventilation control would be possible with an absolutely tight cladding and using mechanical ventilation systems and air-to-air heat exchangers, but this is too complex a subject to discuss here.

A more cogent consideration is whether the process of seasonal wetting due to air leakage causes any physical damage to buildings. Cases of brick and mortar spalling from this cause have been observed just below roof level, where the outward pressures are the highest. Glazed bricks are frequently spalled in the upper storeys of buildings. Brick and stone facings have been known to be pushed outward by accumulated ice on supporting angles.

Ties have been corroded and in at least one case conduits and electrical fixtures embedded in masonry behind the insulation were found to be filled with water. The majority of buildings do not exhibit such damage and there is no recorded evidence that damage caused by air leakage is widespread. Where they do occur, the building is often carrying higher than normal relative humidity. In cold weather the relative humidity in the average residence is likely to be in the 20 per cent range, which may protect them to some degree from excessive effects of moisture from air leakage condensing within walls. With the increasing use of humidification in buildings, and high density, more humid, occupancies such as senior citizens' residences, relative humidities in the 35 to 50 per cent range are becoming more common, and it is questionable whether a dry interior can be relied upon. Also, many modern high-rise buildings are relatively new and the long-term effects of air leakage on such buildings is unknown.

It is reasonable to suggest that buildings should not be excessively leaky and designers should look for obvious paths of air leakage and minimize them as economically as possible. This is important if only to prevent the aesthetically disfiguring seasonal wetness and unnecessary efflorescence on buildings (Figs. 15 and 16).

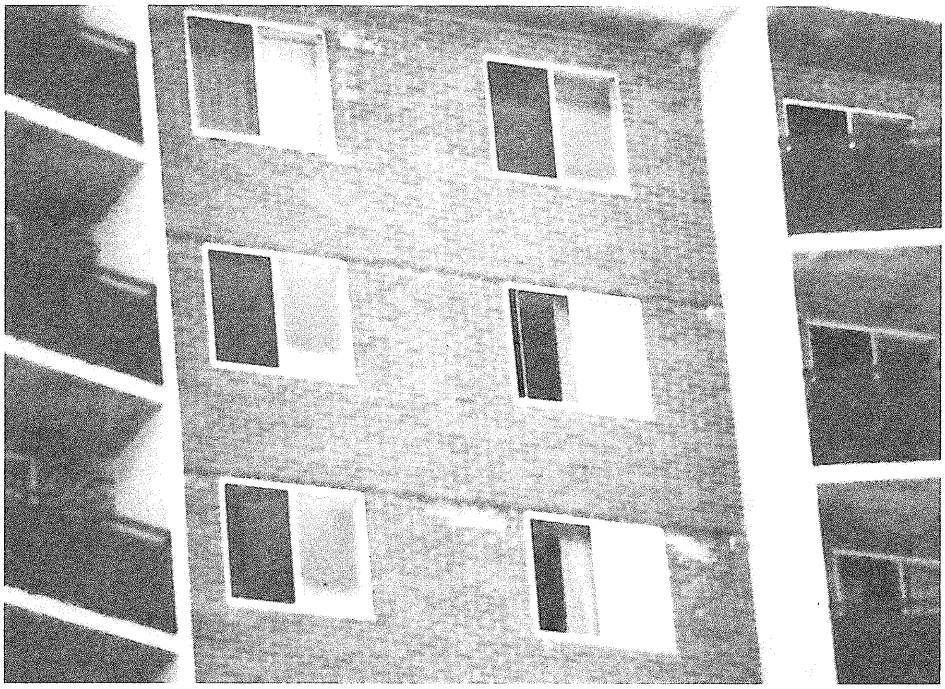


Fig. 15 Example of air leakage on the side of a building

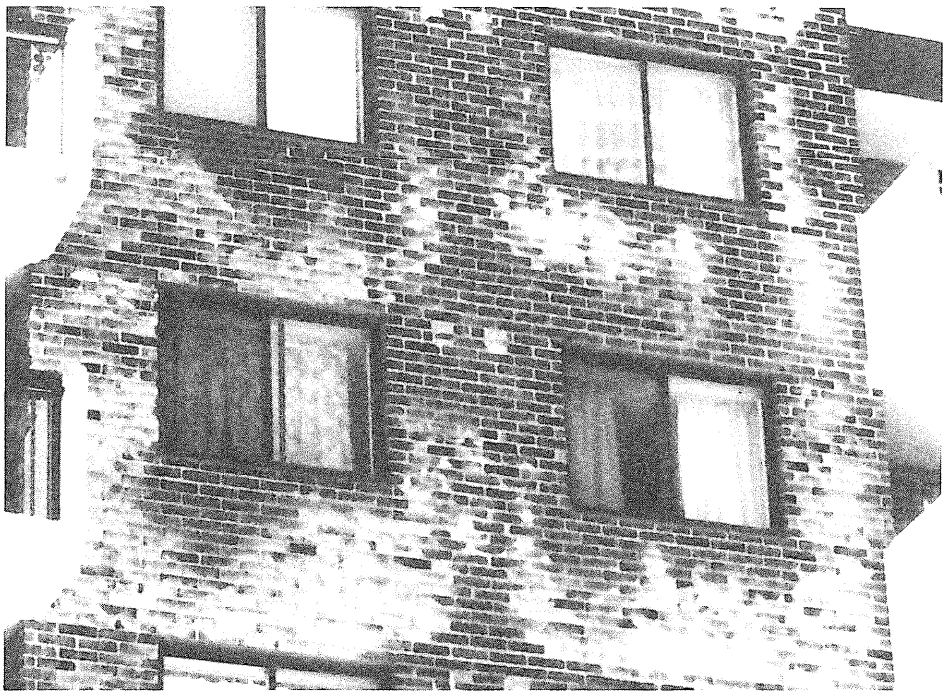


Fig. 16 An example of extensive wetness and efflorescence

5.7 Discussion of Vapour and Air Tightness of Example Wall Assemblies

For cavity and veneered walls alone, it is not practicable to discuss all possible materials and their arrangement to obtain vapour and air tightness, but the following selected examples illustrate an approach to the general problem.

Wall with internal insulation: Fig. 17 shows the case of brick veneer on a concrete block backup wall. Flashings and weepholes would have to be added to complete the rain resistance of the wall. The insulation is applied to the inside of the backup wall and in this instance a flexible, membrane-type vapour barrier is indicated. If the insulation is cemented to the blockwork, the adhesive should not form a second vapour barrier to trap any moisture that does manage to penetrate to the cold side of the insulation. Spot adhesion and/or mechanical fastening would eliminate this potential problem.

Although the wall has been made vapour resistant, it is clear from Fig. 17 that there will be many air leakage paths unless something more is done. The concrete blockwork will be air permeable and it is not unlikely that the joints between the wall and the columns, slabs and cross-walls will be only partially filled with mortar. Shrinkage cracks will also occur at these junctions and several cubic metres per minute of air per metre can penetrate a crack less than 1 mm in thickness under stack effect pressures.

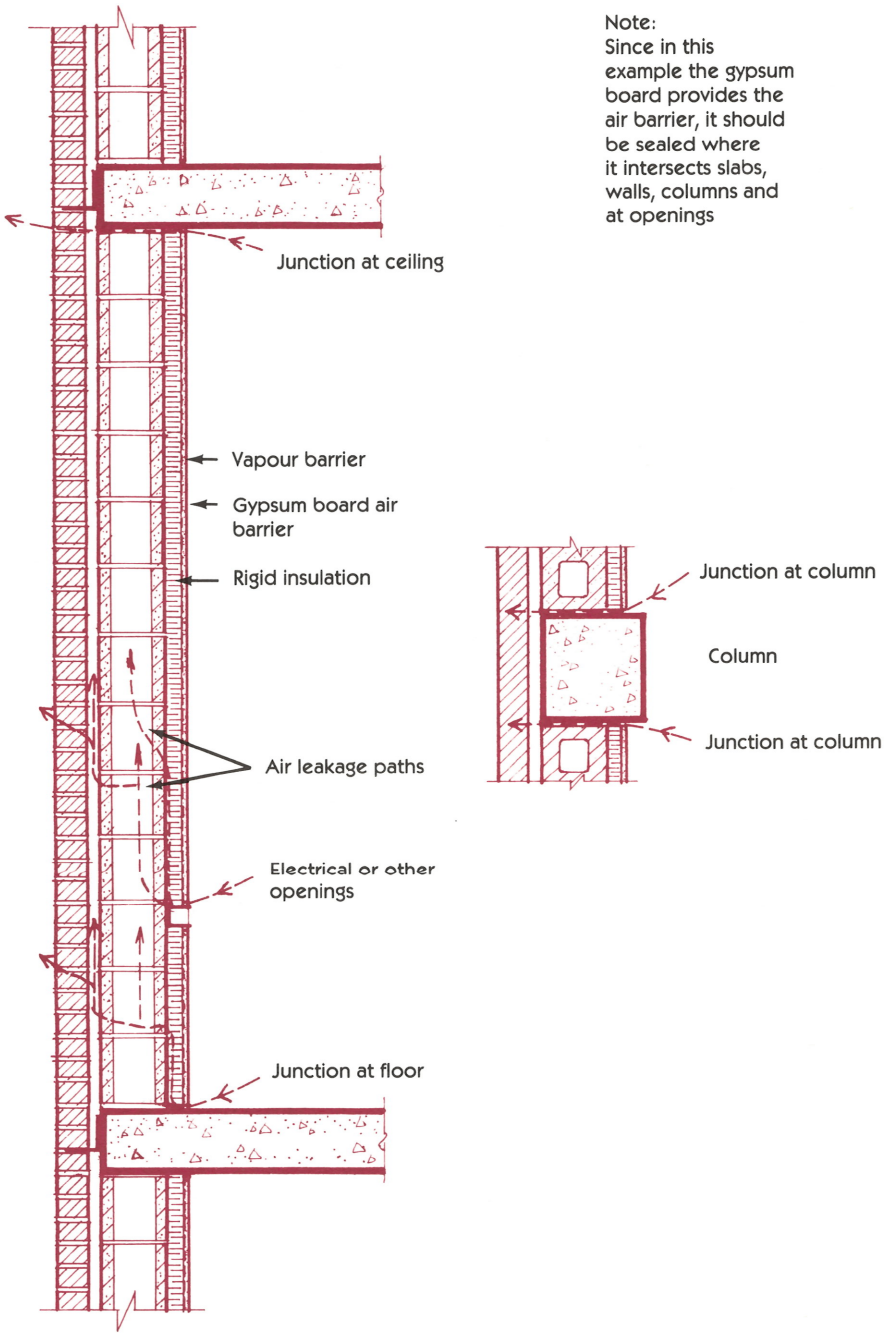

Note:
Since in this example the gypsum board provides the air barrier, it should be sealed where it intersects slabs, walls, columns and at openings
Junction at ceiling
Vapour barrier
Gypsum board air barrier
Rigid insulation
Air leakage paths
Electrical or other openings
Junction at floor
Junction at column
Column
Junction at column

Fig. 17 Air leakage paths in brick veneer on concrete block backup to be taped or otherwise sealed (ties, flashings and weepholes not shown)

The insulation may not be a good air barrier. Open fibre types are air permeable, as are some cellular plastics. If rigid insulation is not air permeable, it would have to be carefully taped at all joints and breaks, as well as all around its perimeter at the intersection with other materials, to act as the air barrier.

The membrane vapour barrier will be an airtight material, but as an air barrier it will be difficult to ensure airtight seals at all laps and edges as well as to keep it free from gaps and tears. Also, where it crosses openings and cracks, it should be supported by other more rigid materials to prevent bulging and gaps under the air pressures.

The best potential air barrier in this design is the gypsum board. Taped joints at all edges will seal them, and gaps around any ducts or fixtures that penetrate the dry-wall should also be tightly sealed. The joint at baseboard level is very important since tests have shown (Ref. 18) that up to half of wall air leakage originates at this point. Figure 7 shows a sealant at the base of the gypsum board.

It may be easier to obtain airtightness by parging the back of the blockwork with a cement mortar (Fig. 18). It will be a good air barrier if it is continuous and free from cracks; this will be more reliably achieved by applying two coats. A sealant should be applied around the perimeter of all panels since shrinkage of the concrete blockwork will be reflected in cracks in the parging at this point (Fig. 8).

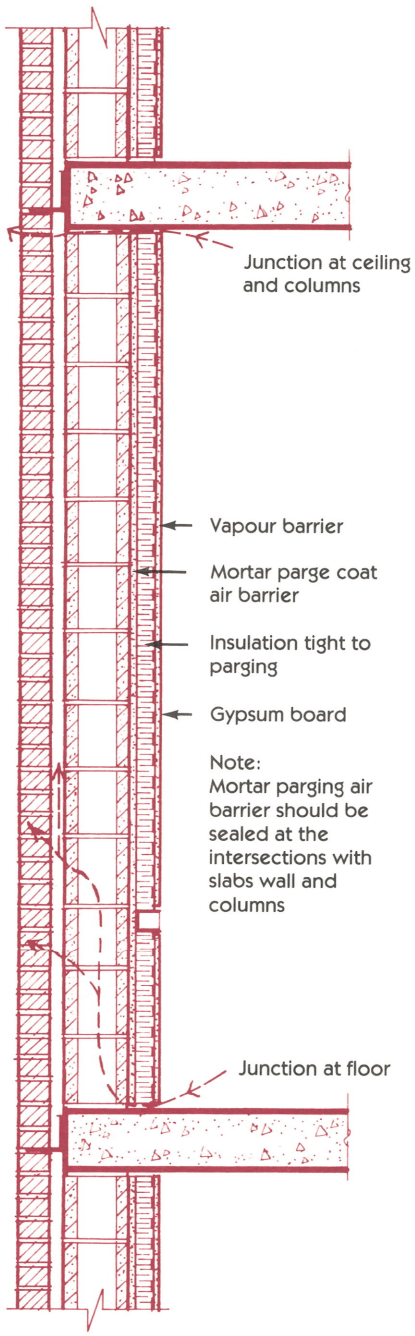

Junction at ceiling and columns
Vapour barrier
Mortar parge coat air barrier
Insulation tight to parging
Gypsum board
Note:
Mortar parging air barrier should be sealed at the intersections with slabs wall and columns
Junction at floor

Fig. 18 Parge coat air barrier requires sealing at junctions with ceiling floor slabs and columns (ties, flashings and weepholes not shown)

Although, ideally, an air barrier should be on the warm side of the insulation, there will not be a flow-through of air with a mortar parging. It will be relatively unaffected by any small quantity of moisture penetrating the vapour barrier and, if the insulation is tight to the parging, there will be little if any movement of air against any cold surface in the space behind the gypsum board. As a bonus, parging will provide additional resistance to any rain leakage that manages to cross the cavity and give a smoother surface for applying insulation.

Insulation in cavity: Figure 19 shows a cavity wall with the insulation placed in the cavity against the inside wythe. A space is left between the insulation and the facing wythe so that rain leakage can drain away.

A mortar coat on the blockwork will be an effective air barrier, provided that all holes and open joints are well covered. Again it will provide a smooth surface for the insulation and extra insurance against rain leakage. A trowelled-on bitumastic coating could be used instead if the blockwork is reasonably even. In either case, the coating should be carried tightly up to the ties or given some special treatment at that point.

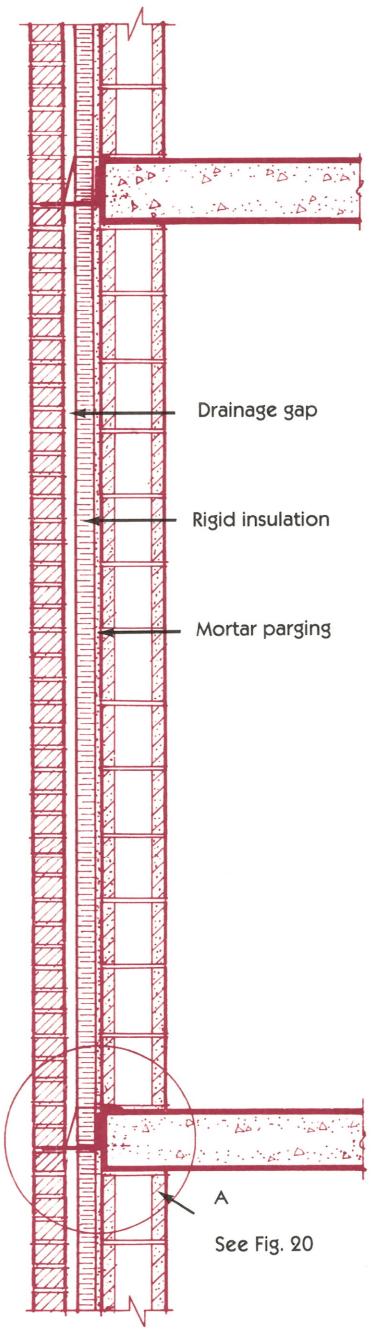


Fig. 19 Cavity wall with insulation in cavity (ties not shown)

The weak point of the system is the junction between the parging and the slabs and columns. Partially filled joints and shrinkage cracks that inevitably form in the mortar and parging around the perimeter of a panel will leak air excessively unless they are sealed in some manner. Figure 20 shows a joint sealed with a flexible sealant. Other alternative details could be used, such as a securely fastened strip of membrane to cover the joint.

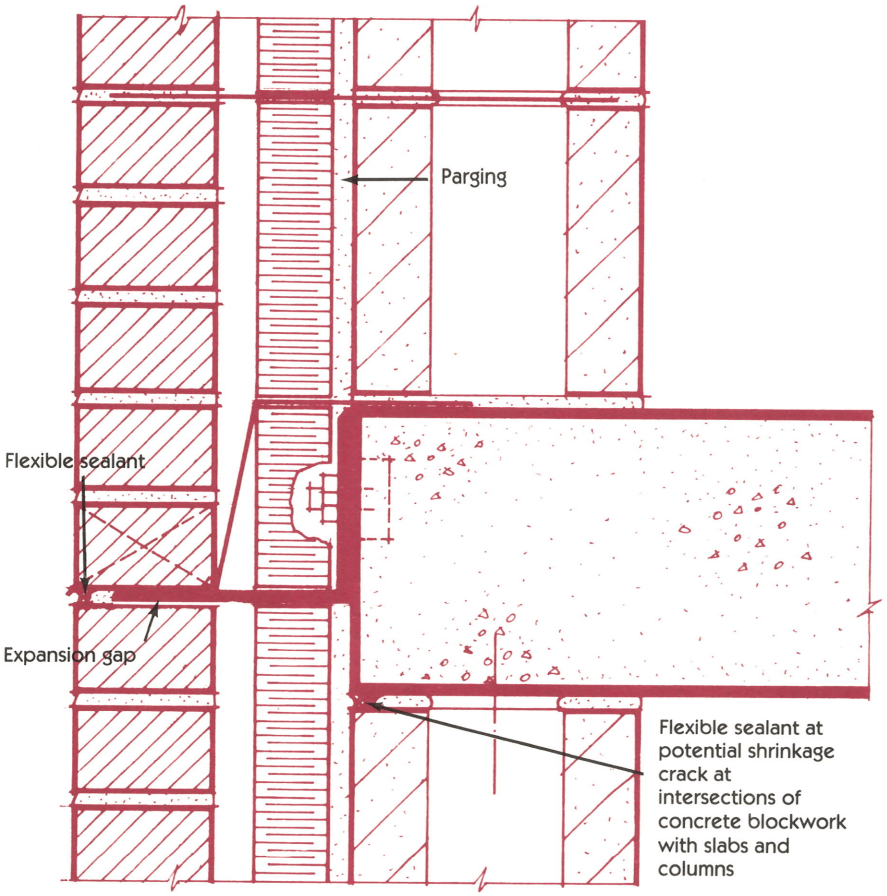

Parging
Flexible sealant
Expansion gap
Flexible sealant at potential shrinkage crack at intersections of concrete blockwork with slabs and columns

Fig. 20 Detail at 'A'

For the insulation to be effective, it must be fastened tightly to the inner wythe. If it is merely stuffed into the cavity, it is of little use since cold air can circulate around it. Spot adhesion is generally unsatisfactory because it frequently comes at least partially loose. The adhesive should be continuous and the insulation ought to be applied before it becomes surface dry or set. This will also help seal any fine shrinkage cracks in the parging and act as a vapour barrier on the warm side of the insulation. Spacer pads of cellular plastic between the insulation and the facing wythe have sometimes been used to keep the insulation in contact with the inner wythe in the event that adhesion is lost.

Note: There should be no theoretical objection to putting the insulation in the cavity and the air and vapour barriers on the inside of the wall, if this would better suit the design.

Steel stud walls: As can be seen in Fig. 21, steel stud backup walls present the same problem as other wall constructions in obtaining a good air seal at all junctions and fixtures. It may be especially difficult to devise a good detail below the ceiling slab since a movement gap should be left at the top of the studs to prevent buckling under floor slab deflections. A 12 mm gap at this point is also a code requirement to allow for the expansion of the studs during a fire (NBC 9.25.3.3. RS 25C(3)).

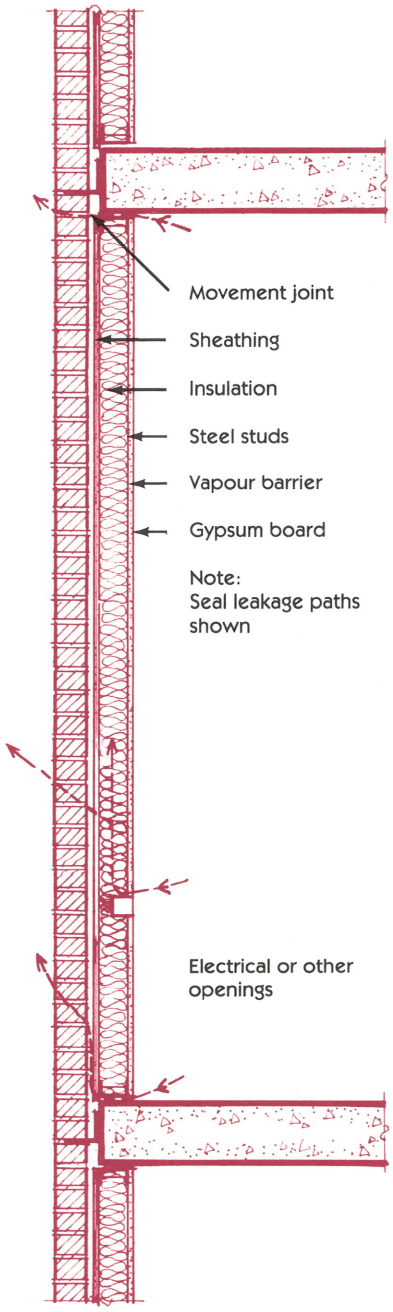


Fig. 21 Air leakage paths in brick veneer on steel stud backup (ties, flashings and weepholes not shown)

Some studs require the addition of a sheet material screwed to both sides of the studs to give them stability, and certain designs employ gypsum board on both the internal and the cavity sides. Yet there is a danger of this getting wet from rain or condensation and rapidly losing its structural value. To help avoid this, building paper must be placed on the gypsum board and lapped over the flashings to arrest any moisture that crosses the cavity. However, it should be a vapour permeable type to avoid trapping moisture passing the internal vapour and air barriers.

Drop ceiling spaces: Figure 22 shows schematically the situation above hung ceilings. Insulation, vapour barriers, and air barriers must be continued through the ceiling to the underside of the floor slab to prevent moisture and air exfiltration. Interior dampness and paint lifting have sometimes been traced to condensation in this zone.

Windows: The joint between window frames and the wall construction is responsible for a great deal of air leakage and is discussed separately on page 52.

General: Some of the measures suggested above differ from present practice, but unless the questions of moisture and air leakage are addressed directly, the performance of building envelopes will not be improved.

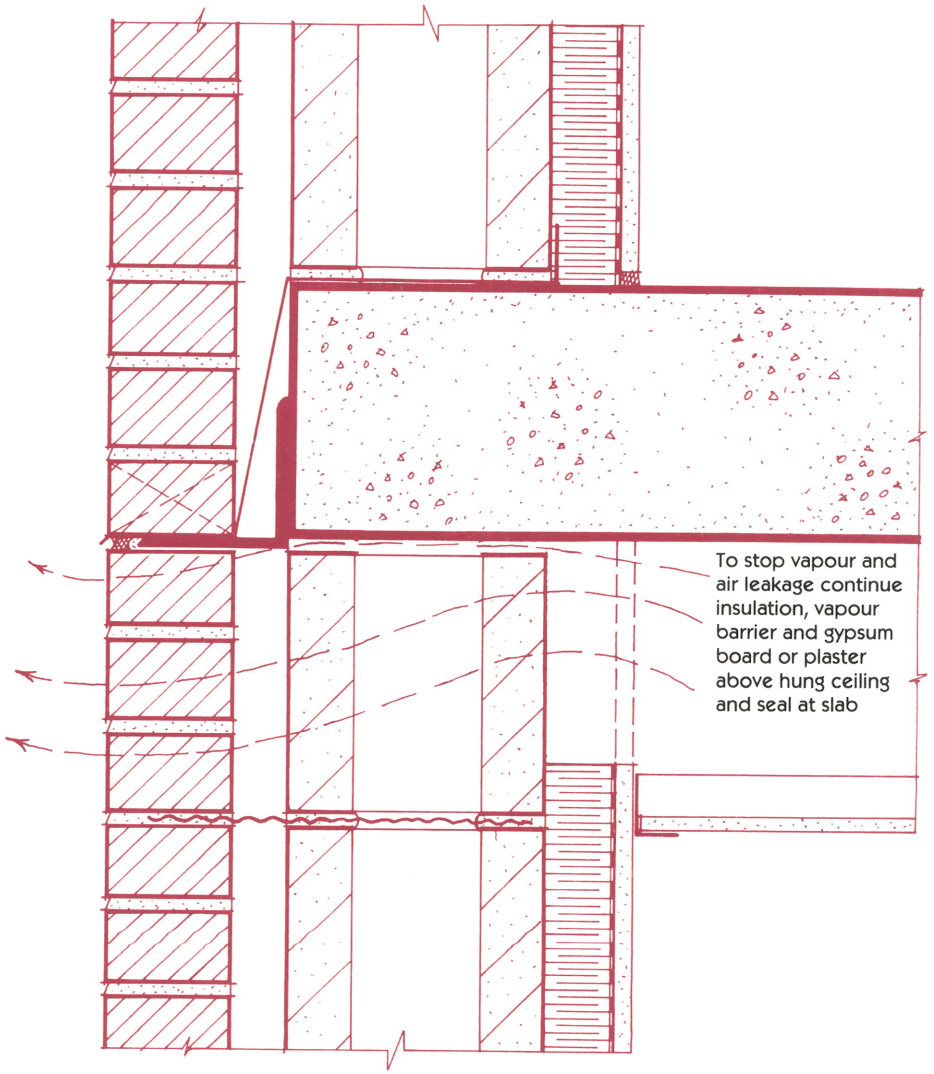

To stop vapour and air leakage continue insulation, vapour barrier and gypsum board or plaster above hung ceiling and seal at slab

Fig. 22 Potential condensation zone above hung ceiling

5.8 Movement Control Joints

The dimensional changes in wall materials were pointed out in a previous section and approximate values of the movements were given. Stresses can build up in a material if its dimensional changes are prevented, which may cause it to crack, crush, or buckle, depending on whether the material is contracting or expanding. This happens when two materials of different movement properties are too rigidly joined. It also occurs where a thinner or weaker element meets a stronger, unyielding one. Small movements build up into large ones over long runs of material. This is sometimes observed where a railing has cracked or has pulled away from its supports. Metal copings with insufficient provision for movement will buckle.

Provision for movement is part of design. In general, building elements may be made either strong, flexible, or ductile enough to accommodate movement unharmed, or joints may be provided to permit the movement to take place freely. With brittle materials, such as concrete and masonry, joints are usually the best solution.

Two cases occur in cavity and veneer walls of high-rise framed buildings which in recent years have caused many problems because of the lack of movement joints. These are explained in the following discussions.

Vertical Joints for Horizontal Movements

Consider first a low clay brick wall 30 m long, free to expand along its length. If it was laid up at 20°C, its surface temperature could rise 45° in a hot summer sun or fall 45° in the winter. Including its moisture expansion characteristic, in the summer an average brick wall would lengthen,

Due to 0.02% moisture expansion	6 mm
Due to 45° temperature increase	9 mm
Total	15 mm

Since a wall expands from its centre, it will move 7 mm both ways (Fig. 23(a)).

If, instead of being free, the brick wall were on a concrete foundation, the concrete would tend to increase thermally in length about the same amount for the same assumed temperature change. However, the concrete in a new building will be shrinking and, since it is usually buried in the soil, will therefore be cooler. If so, the foundation will not follow the brick movement completely and, because of friction, will restrain the expansion of the brickwork along the bottom edge. The brick wall will then take a shape somewhat as shown in Fig. 23(b). Generally there will be some slip towards the end of the wall and the brickwork will overhang the foundation a small amount. In slipping, it usually tears away a small piece of concrete (Fig. 23(c)). In even longer walls, the strains could cause the type of cracking shown in Fig. 23(d).

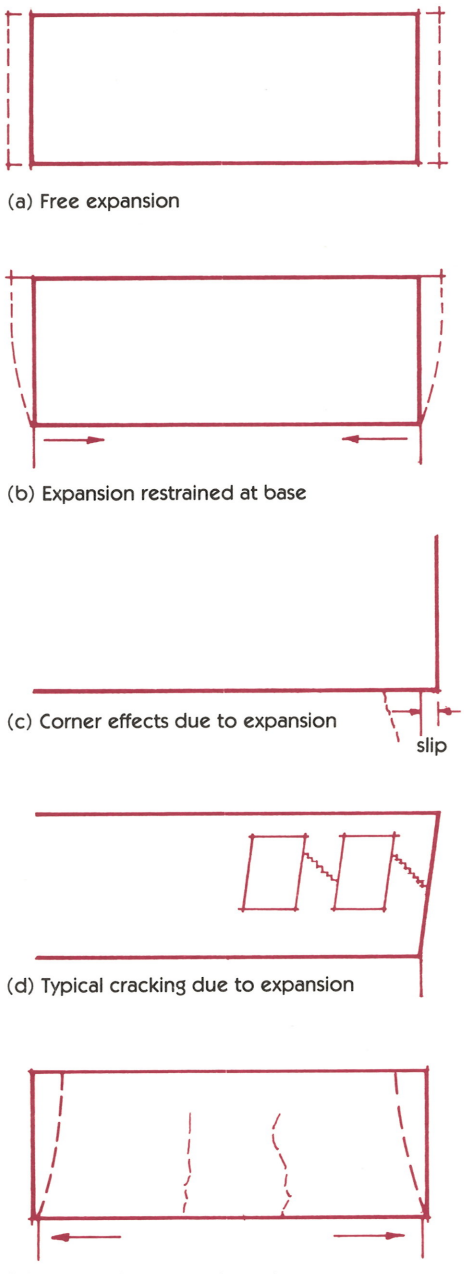
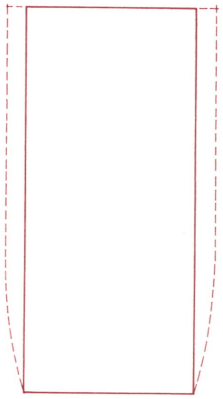

(a) Free expansion
(b) Expansion restrained at base
(c) Corner effects due to expansion
slip
(d) Typical cracking due to expansion
(e) Contraction - restraint at base

Fig. 23 Effects of expansion and contraction on low masonry walls

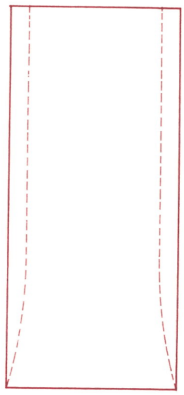
If the temperature of the brickwork subsequently falls to -25°C or lower in the winter, the overall reduction in temperature will be about 90°C. This large drop from extreme summer conditions will shorten the brickwork 8 mm at each end, and the wall will tend to take the shape shown in Fig. 23(e), unless the base of the wall is able to slip along the foundation. Generally, however, there will be some roughness between the concrete and the brickwork, and the restraint of movement can cause large tension forces. Brickwork is weak in tension and one or more cracks may occur in the wall.

Whether or not such cracks appear depends on the materials involved, the climate, the direction the building faces, the length of the wall, and even the colour of the brick. If the mortar is not too rigid, say 1:1:6 cement-lime-sand mix (or an equivalent masonry cement mortar), the tensions may be partially relieved by many fine unobjectionable cracks in the mortar joints, which are to some extent self-healing. This cannot be entirely relied upon, however, and in long walls it is advisable to provide expansion/contraction joints at frequent intervals. (A similar analysis and conclusion applies to concrete masonry, taking into account the fact that concrete has higher thermal movements and shrinks.)

A multi-storey wall under the assumed temperature variations would tend to take the shapes shown in Fig. 24. The effect of foundation restraint would dissipate within a storey or two of the base. If the upper part of the wall were able to expand freely, it seems that movement joints would be required only at the bottom. The floors and the frame of the building will not have the same temperature variation, however, and will also resist the wall movements. This will cause tension in the masonry at cold temperatures, which makes it advisable to extend movement joints through the whole height of the building.



(a) Rising temperature



(b) Falling temperature

Fig. 24 Effect of free expansion and contraction of exterior brick wythe of high building

In cavity and veneer walls on steel or concrete frames, a particular condition occurs at the building corners. The building frame and backup wythe will not move as much as the facing wythe. As the brickwork contracts and expands, it is drawn into or forces itself away from the corner column, as shown in Fig. 25. This is a common contributing cause of the cracks often seen at the corners of buildings. Vertical shortening, which is discussed later, can also give rise to cracks.

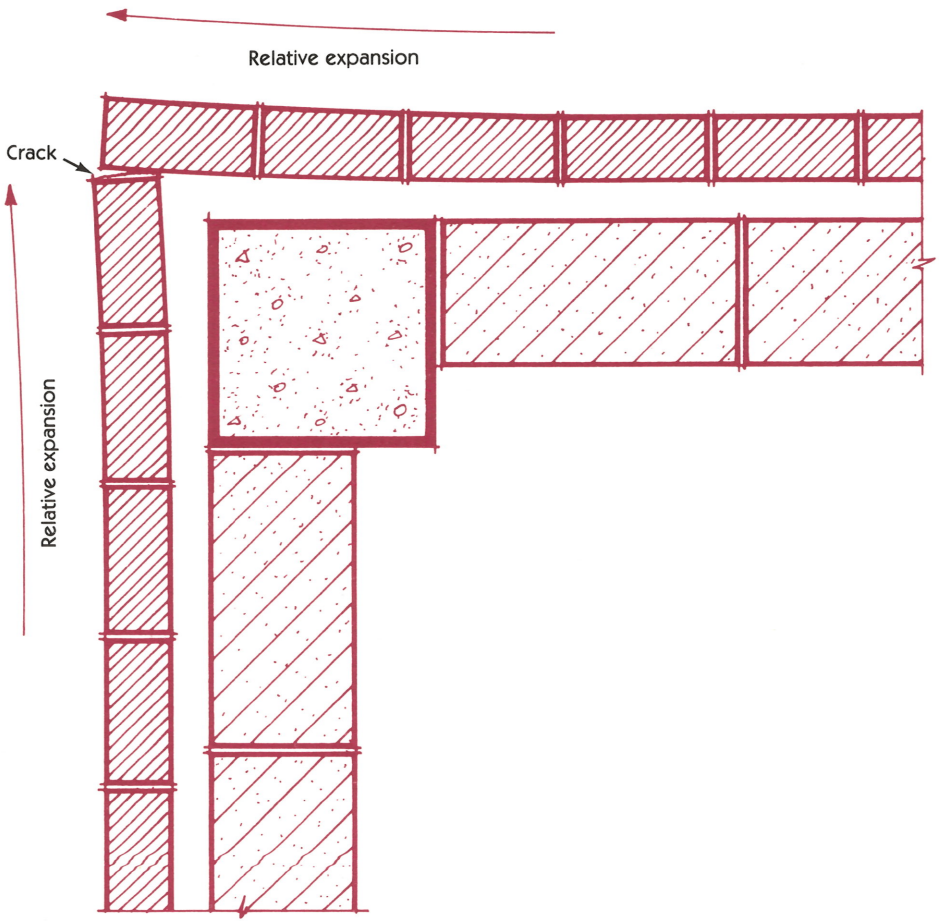


Fig. 25 Effect of expansion at corner

Another point where expansion may cause cracking is at offsets in the building face. A long wall expanding into such an offset can cause a crack such as "X" or "Y" in Fig. 26, unless the movement is accommodated by an expansion joint near or at "A".

Parapets having maximum exposure and the least weight and restraint are sometimes seen to overhang the wall or show a crack, such as in Fig. 27. The usual recommendation is that expansion joints in the wall be extended through the parapet and that further joints also be made so that the joint spacing in the parapet is half that in the wall (Ref. 22).

The optimum choice between the minimum number of movement joints and the avoidance of cracking requires computation, tempered by judgment and experience with the materials, the form of the building, and the climate. There are few well-established, simple rules, but evidence based on observation, opinion and research (Refs. 23 and 24) indicates that the movement joint spacing in the outer clay brick wythe of a cavity wall or veneer should not exceed 12-15 m. Concrete block facings require closer spacings of about 10 m.

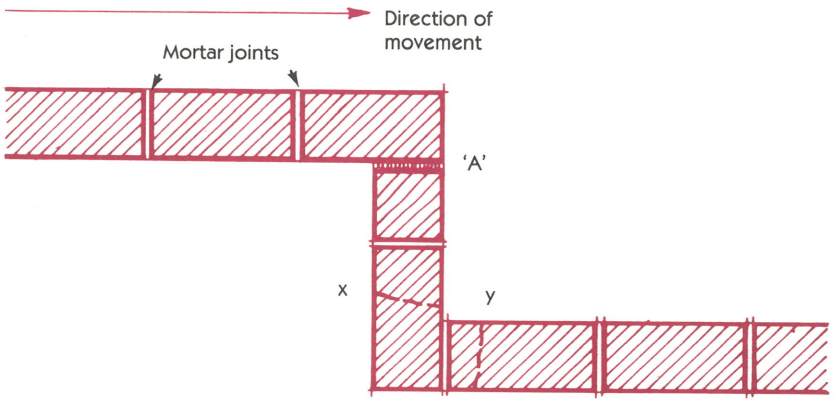


Fig. 26 Expansion joint at an offset

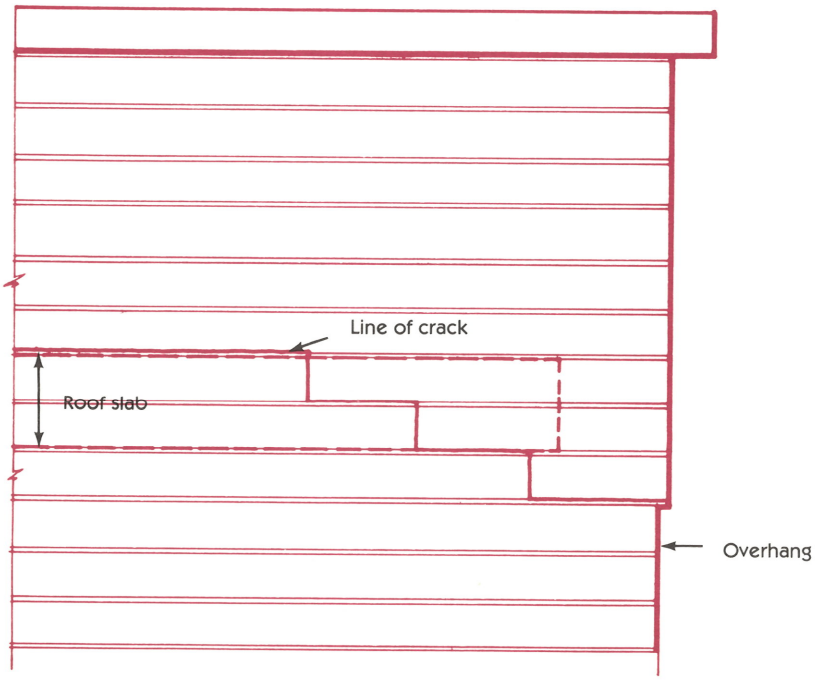


Fig. 27 Effect of parapet expansion

Special investigation and experience may justify greater distance between joints on straight runs, but particular attention should always be paid to offsets and corners and any obvious changes in rigidity, as, for example, where a wall intersects another more rigid part of the building or another building. Joints should always be provided where a long run of brickwork expands into an outside corner. These may be placed right at the corner or at some convenient location within about 8 m. (Ref. 23).

Joints in the facing wythe of cavity walls and veneers on structural frames are often made opposite columns or cross-walls, so that the two sides of the joint can be anchored to the support with flexible ties (Fig. 28).

Further discussion of vertical joints for horizontal movements may be found in References 22-25. The Brick Institute of America, *Technical Note on Brick Construction, No. 18*, recommends that they be placed in long walls and at offsets, junctions, corners and parapets (Fig. 29).

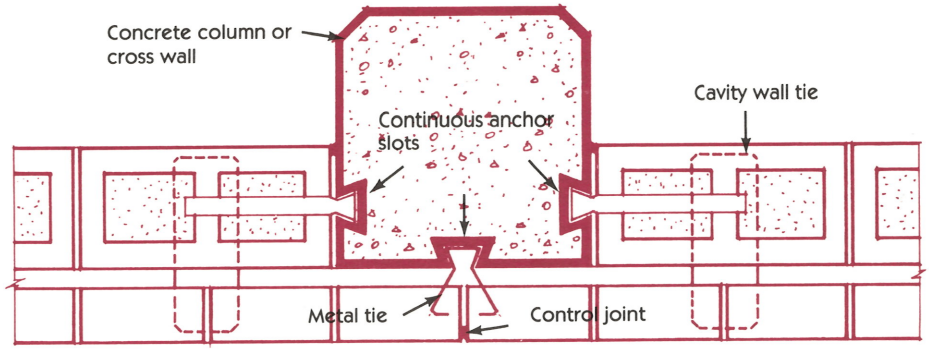


Fig. 28 Movement joint at column

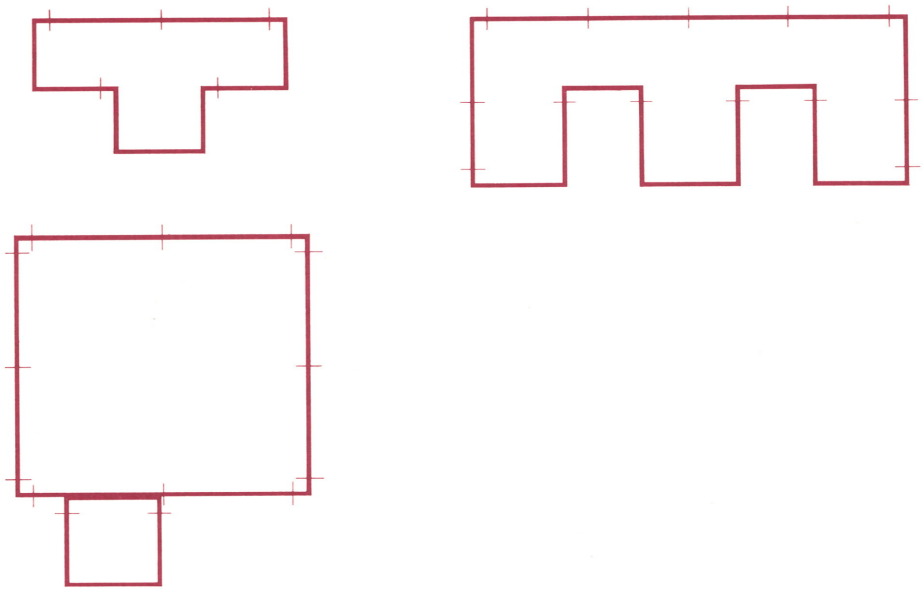
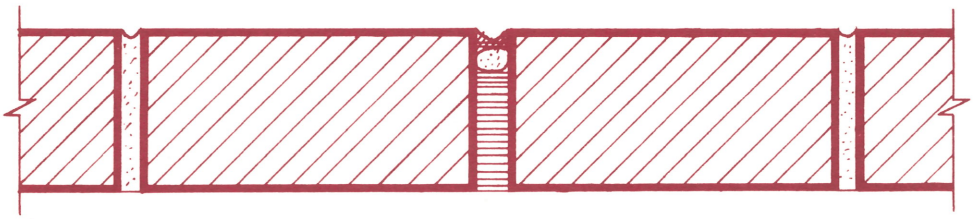


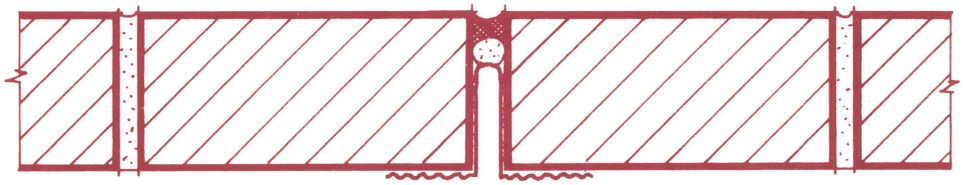
Fig. 29 Typical locations of movement control joints

Width and Filling of Expansion Joints

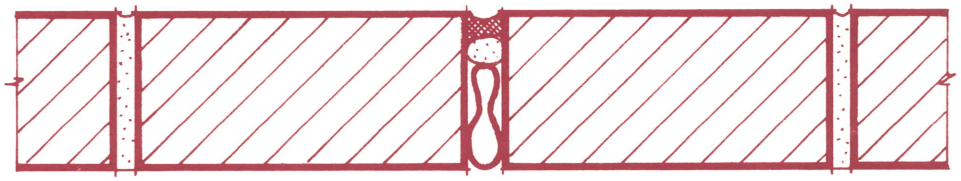
Expansion joints must be closed to exclude the weather. Generally this closure consists of a backup compressible filler covered with a flexible sealant. Both the filler and sealant must have enough compression capacity to accommodate the movement of the masonry into the joint. It must also be able to rebound when the movement reverses, producing tension in the sealant. Typical joint designs are shown in Fig. 30. (See also Sealants, page 55.)



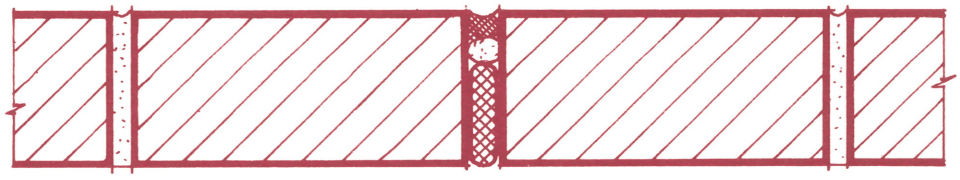
Copper



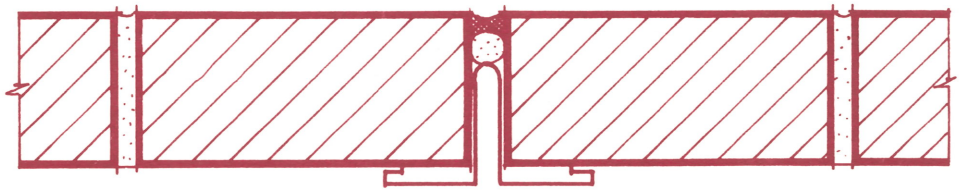
Premoulded foam rubber or plastic



Neoprene



Extruded plastic



Asphalt impregnated fibreboard

Fig. 30 Expansion joint fillers

Horizontal Joints for Vertical Movements

Until recent years, it was not generally recognized that there should also be movement joints in the exterior wythes of cavity or veneered walls at the shelf angles. Failure to provide these has caused many problems of spalling, buckling, and, in some cases, dislodgement of whole panels of brickwork (Figs. 2 and 3).

The mechanism can be explained by reference to Fig. 31, which shows the reinforced concrete frame and the brick facing wythe of a 10-storey building. From the elastic and creep deformations produced by loads and concrete shrinkage, the structural frame may shorten 15 mm or more. At the same time, the facing wythe may have a moisture and thermal expansion of about 15 mm, so that the theoretical difference in height between the cladding and the frame could be about 30 mm. Such a differential movement, if it occurred, would put a severe strain on the cavity or veneer ties at the top of the building. If, however, the shelf angles are mortared solidly into joints at each floor level, they will bear on the brick facing and try to force it to follow the downward movement of the frame. The result is that the facing is subjected to heavy compression. In many cases this stress causes brickwork facings to spall or buckle outward, as is explained in Canadian Building Digest No. 185 (Ref. 26).

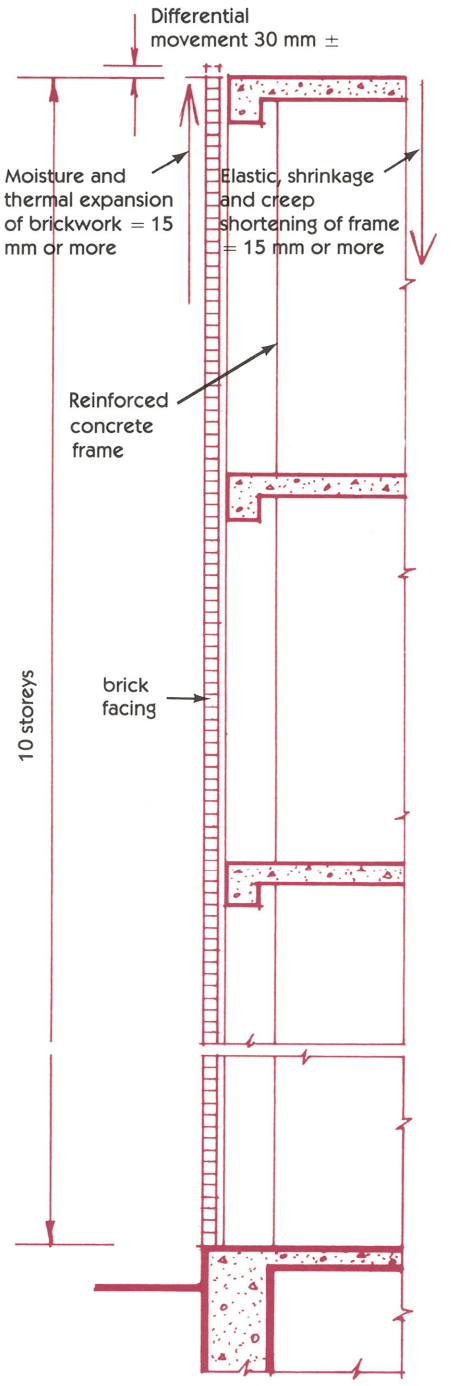

Differential movement 30 mm ±
Moisture and thermal expansion of brickwork = 15 mm or more
Elastic, shrinkage and creep shortening of frame = 15 mm or more
Reinforced concrete frame
brick facing
10 storeys

Fig. 31 Difference in height of brick facing and frame if relative movements unrestrained

The solution to both potential problems is to provide an open gap (or one filled with a compressible material) below the shelf angle, and to point the mortar joint at the toe of the angle with a flexible sealant (Fig. 32). The width of the gap below the angle should be determined by the designer, but is typically 3 mm to 6 mm to accommodate the differential movement over one-storey height. (References 23 and 27 provide guidance for the calculation of gap widths.)

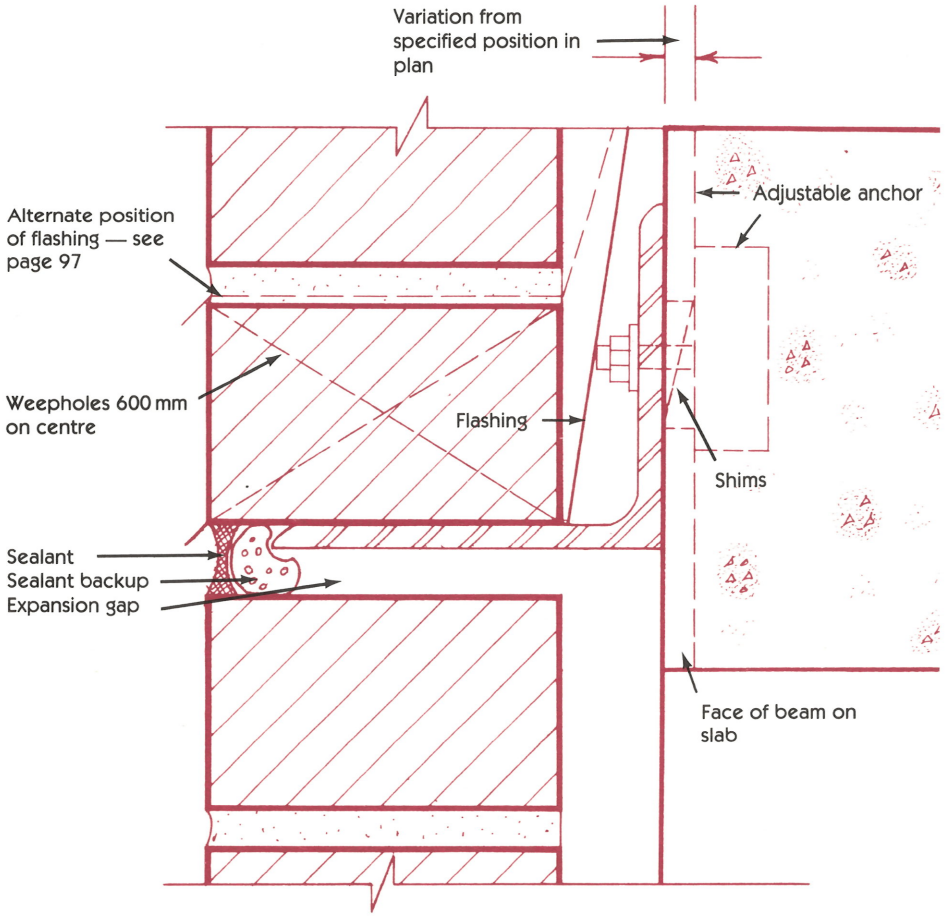


Fig. 32 Detail of joint sealant and expansion gap at shelf angle (Ref. 27)

Where this precaution is not taken, spalling is sometimes caused by the concentration of stress where the pointing mortar is pinched at the toe of the shelf angles (Fig. 33). When buckling occurs, it is due to instability of the thin facing wythe under eccentric loads from the shelf angles (Fig. 34). Examination of several cases of outer wythe buckling revealed that some of the ties were missing or were incorrectly placed. While this was not the prime cause of the problem, it was evidence of substandard construction.

It has also occurred that the first row of ties was too far from the shelf angle both above and below. As is shown in Fig. 34, this can leave too great a length of facing without positive anchorage. In the case illustrated, a dovetail anchor at the spandrel beams would improve the situation. Half-height units at the top and bottom of walls to reduce the distance between ties has been suggested (Ref. 31).

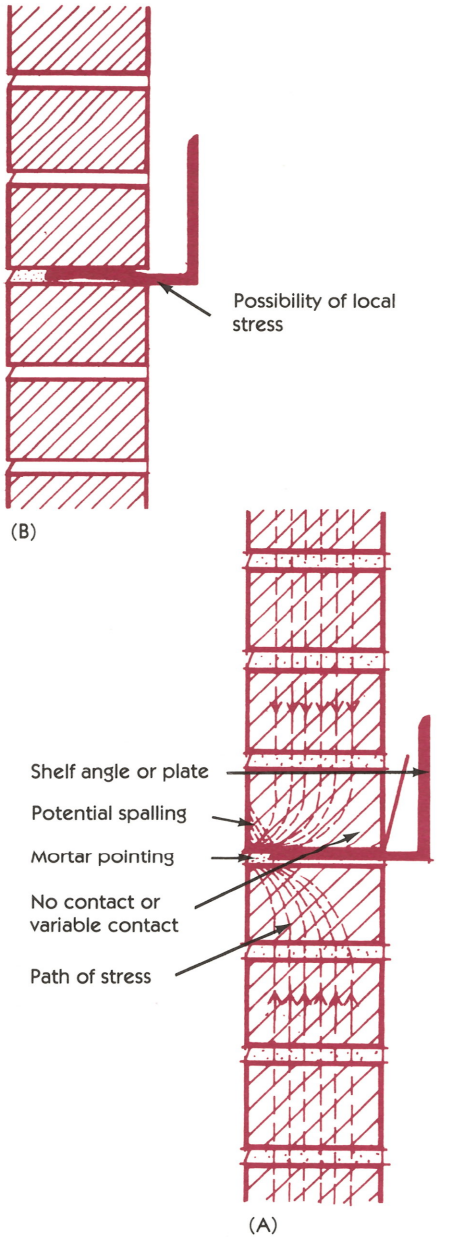


Fig. 33 Spalling due to mortar pointing of bed joint in facing wythe at shelf angle

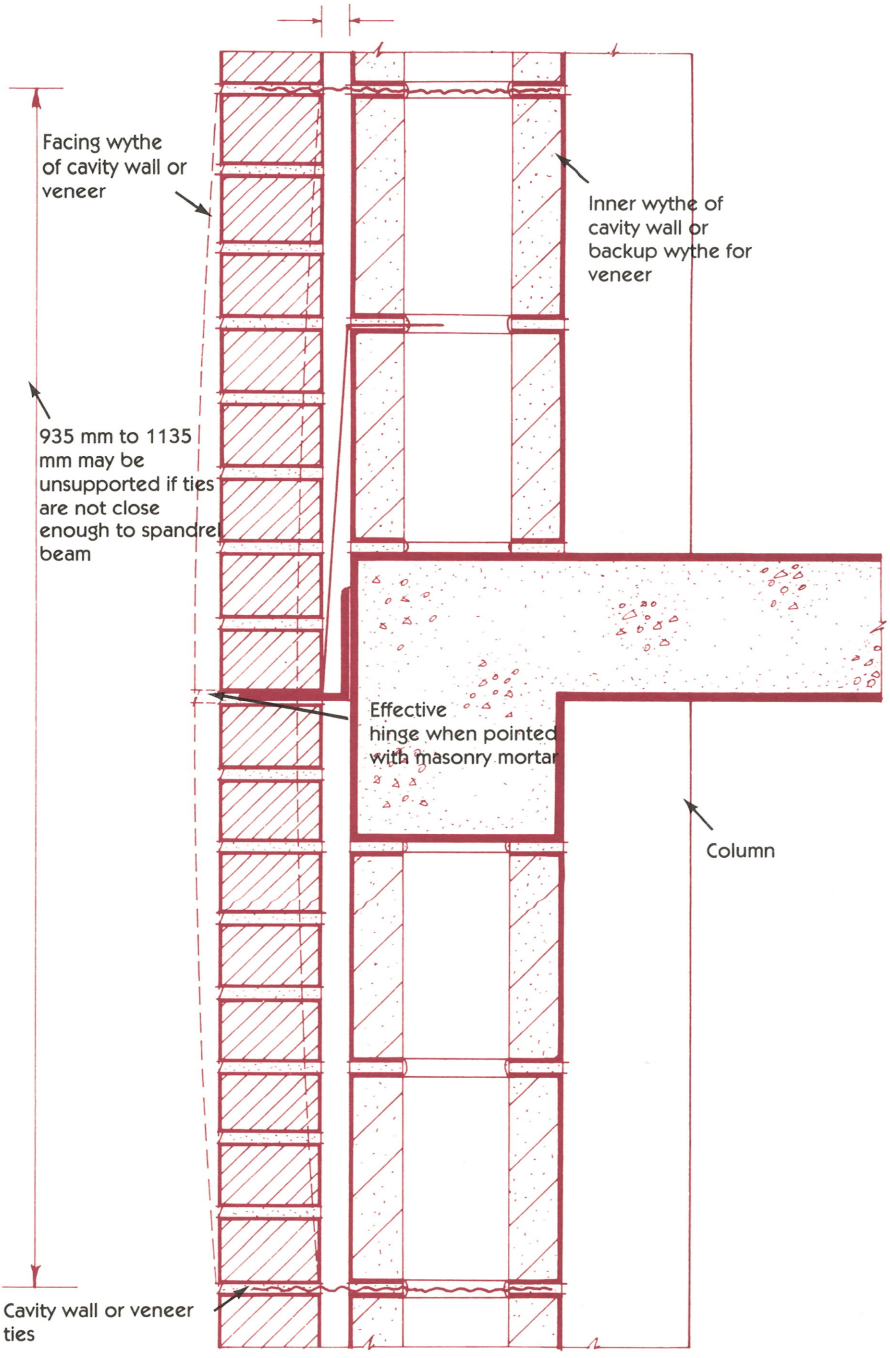

Facing wythe of cavity wall or veneer
Inner wythe of cavity wall or backup wythe for veneer
935 mm to 1135 mm may be unsupported if ties are not close enough to spandrel beam
Effective hinge when pointed with masonry mortar
Column
Cavity wall or veneer ties

Fig. 34 Typical cavity wall and veneer construction showing one manner of buckling

CHAPTER 6. DESIGN DETAILS AND COMMON DEFICIENCIES

6.1 General Observation

When a masonry wall has moisture problems, spalled bricks, cracks, or other signs of deterioration, there has to be a reason. It may be a material problem, faulty workmanship, or a poor design detail. Often the source of the trouble may be obscure since there is usually more than one cause, all or partly hidden within the wall.

Unless the causes of problems are identified, effective repairs and future prevention are at best uncertain. In diagnosing present problems or in designing against future ones, therefore, it is helpful to be aware of adverse factors known to have caused trouble in the past. This chapter discusses a number of design details and some common deficiencies.

6.2 Flashing

Cavity walls and veneers are designed on the assumption that even well-constructed 100 mm facing wythes will leak. At certain key points flashings are necessary to keep water out of the wall or to direct whatever does get in back to the exterior. A flashing may be an exposed, impervious sheet material covering the surface of masonry, such as the back of a parapet, or an internal flashing within the masonry. Locations that require flashing are, for example:

- the bottom of all cavity spaces, to intercept any water running down the inner surface of the facing wythe
- over-shelf angles to direct water outwards and to protect the angles from corrosion (Figs. 5,7,10,11)
- at foundation level (Fig. 35)
- at the intersection of walls with horizontal surfaces, such as roof decks and balcony slabs (Fig. 36)
- sills made of pervious or jointed materials, such as brick, stone, or precast concrete, should be flashed on the underside (Fig. 44)
- parapets (page 46)

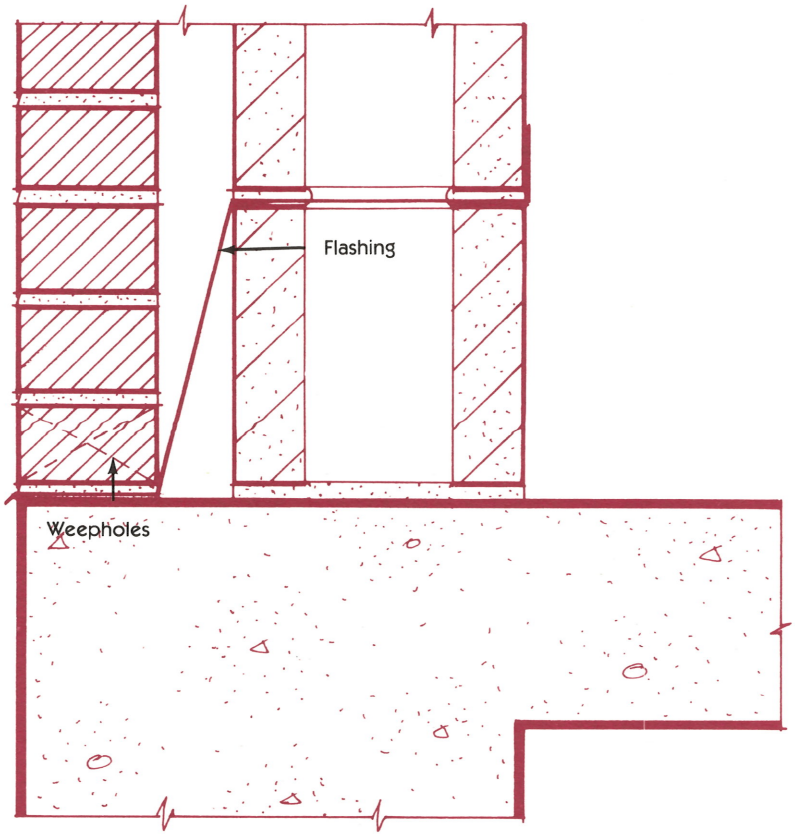


Fig. 35 Flashing at Foundation

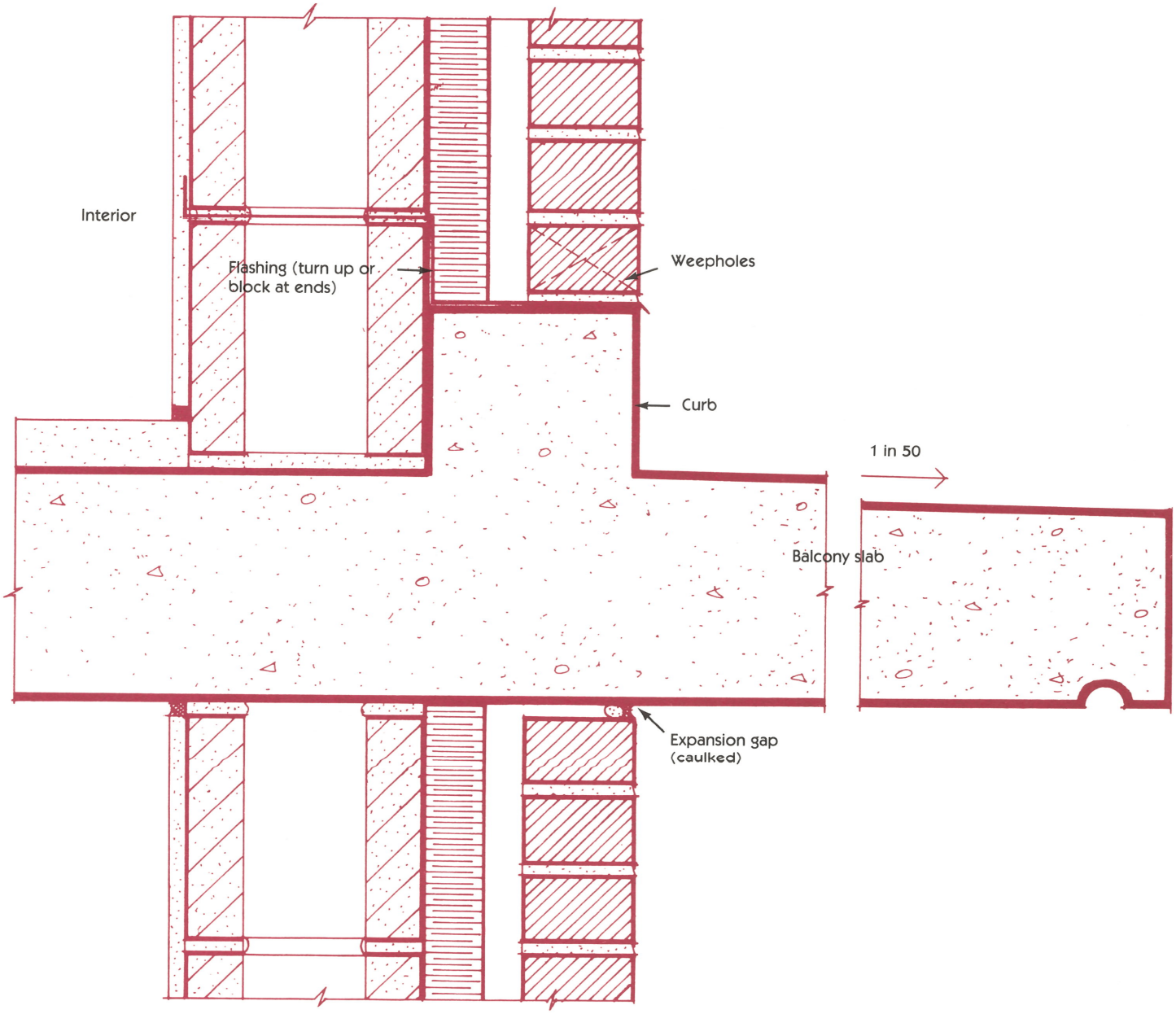


Fig. 36 Flashing and drainage of balcony

Flashing Materials

Materials for flashing should be impervious to water, easily formed to shape, durable under the environment, not brittle at cold temperatures, and not easily torn or punctured. Sheet copper in preformed shapes, with soldered joints and provision for expansion, is widely recognized as a very satisfactory flashing material. Other metals, such as galvanized sheet steel, aluminum, or lead, can be corroded by mortar and should have protective coatings (Refs. 4 and 29). Materials less costly than metals are most often used. These include bitumen impregnated fabrics, plastics, and thin copper laminated to carriers such as plastics and bituminous membranes. Unequivocal statements as to the desirable minimum qualities of flashing materials are scarce, other than that they should be of good quality. CSA Standard A371 does not specify flashing materials but states that the following are typical:

- sheet lead (1.73 mm minimum thickness)
- galvanized steel (0.33 mm minimum thickness)
- copper (0.36 mm minimum thickness)
- polyvinyl chloride (0.5 mm minimum thickness)
- copper (60 g/m^2) laminated to felt or kraft paper.

Flashing Continuity

Flashings should be continuous over the members they are meant to protect and should be lapped and sealed at joints (Fig. 37), except that metal flashings require slip joints at intervals to allow for expansion and contraction. Wherever a flashing abuts a column or crosswalk, or projects into a cavity, as at the end of a sill, it should be turned up at the end and sealed to form a dam or trough to keep water from flowing off the end.

Flashing Deficiencies

Where leakage problems have been caused by inadequate flashings, the following are among the common deficiencies:

(a) Flashing not called for on drawing:
this may result from an oversight, or perhaps the need for flashing was not recognized

(b) Missing flashing:
flashings inadvertently omitted

(c) Missing reglet:
in some designs, flashing is carried up a vertical surface and tucked and sealed into a notch (reglet) preformed in concrete or formed by raking out a mortar joint (Fig.11). If the reglet is missing, it is probable that the flashing will be missing as well (Fig. 37).

(d) Damaged flashings:
flashings may be damaged by wind or rough handling, or may even be carelessly cut off. This can be prevented by supervision and inspection.

(e) Insufficient flashing details:
flashings are often detailed in an oversimplified, partial fashion on drawings without considering the other elements of the building. A flashing as shown in Fig. 32, may run into interference with the shelf angle bolts if the cavity is narrow. A solution sometimes adopted is to place the flashing one or two courses above the shelf angle (Fig. 38). This is feasible, but must be carefully done since any hole in the flashing will drain into a closed space. An even more serious omission is failure to consider the intersection of flashings with columns and other contiguous elements. Figure 39 illustrates gaps in flashings that are likely to occur and are frequently observed.

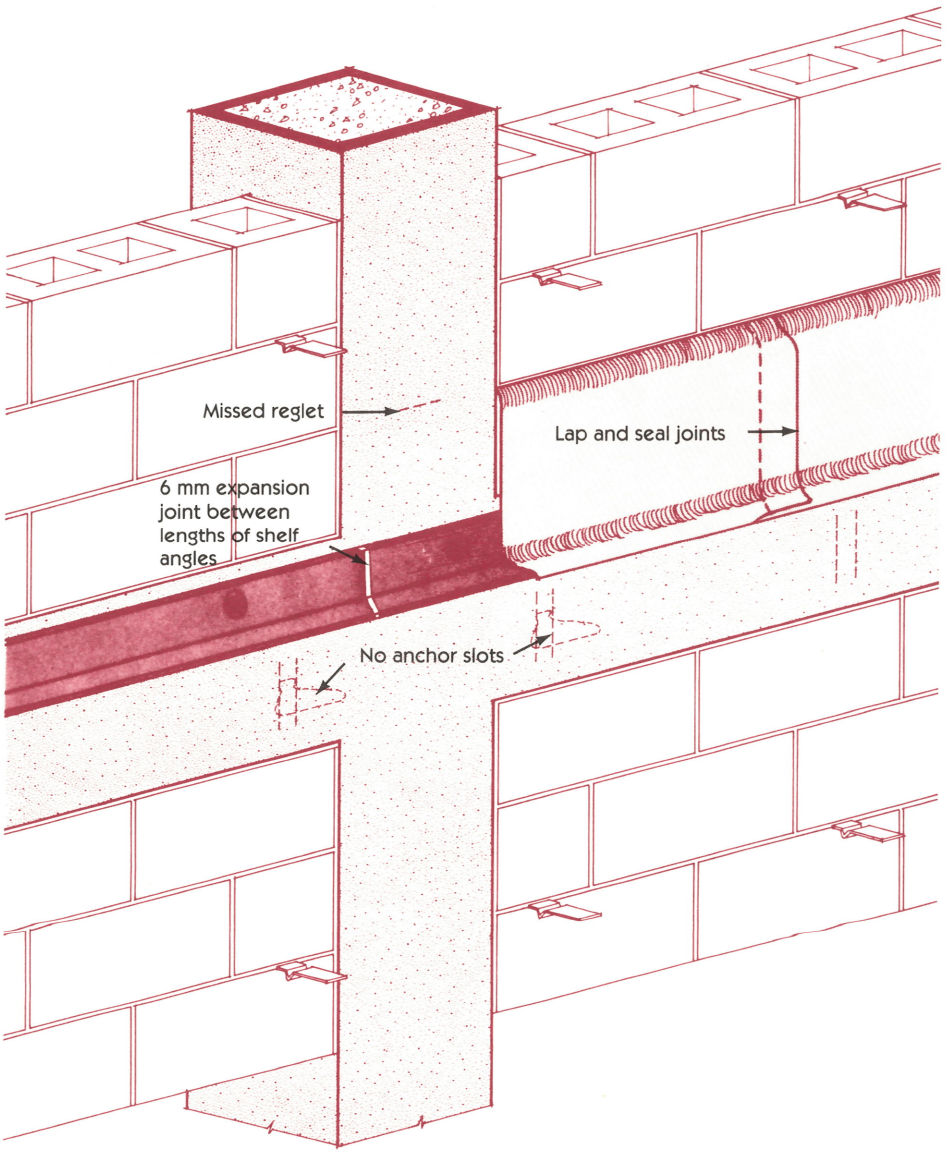


Fig. 37 • The missed reglet often leands to a gap in the flashing
• The missed anchors leave a vertical distance of up to 120 mm without an anchor (Ref. 17).

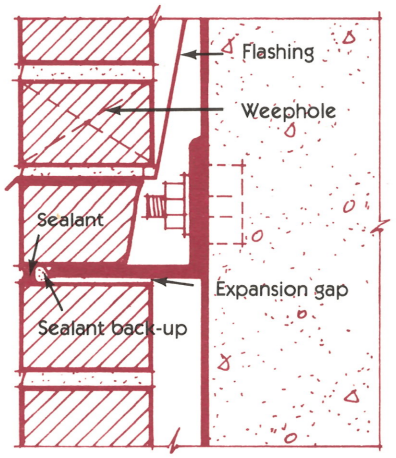


Fig. 38 Flashing raised above shelf angle to avoid bolt interference

Parapet Flashing

Parapets are one of the most exposed parts of a building, and water penetrating them and draining into the walls below has been responsible for moisture problems. Their proper flashing has been discussed professionally for many years. A variety of materials are used and there is no standard parapet design. There is a general opinion, however, that there should be a through-wall flashing below pervious copings such as segmental and stone (Fig. 37) and a similar through flashing near the base of the parapet to intercept water percolating downwards. In modern residential construction, the coping usually consists of a metal cap, which is self-flashing.

CSA Standard A371, Clause 4.14.1, stipulates that parapets be constructed of solid masonry of solid or filled hollow units. Parapets are also required to have through-the-wall flashings and, if they are less than 300 mm thick, to be flashed on the back for their full height, or at least 900 mm above the roof level. This is to take care of the likelihood of snow drifting against the parapet. Figure 41 shows such a parapet. Some designers prefer to omit parapets whenever possible and simply to use well-flashed curbs at roof edges (Fig. 42).

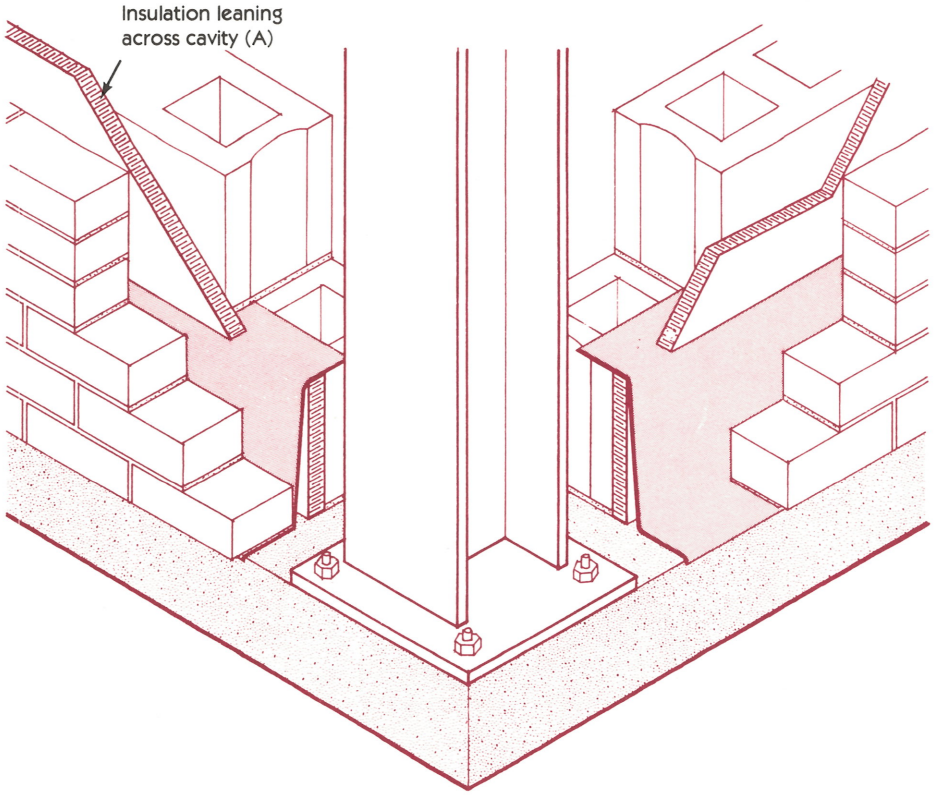


Fig. 39 It is easily visualized how leakage occurs where details like this are encountered. It will be difficult to:

- flash around the column
- anchor the block
- obtain an air barrier
- maintain a cavity
- place the veneer
- maintain a continuous thermal barrier (Ref. 16).

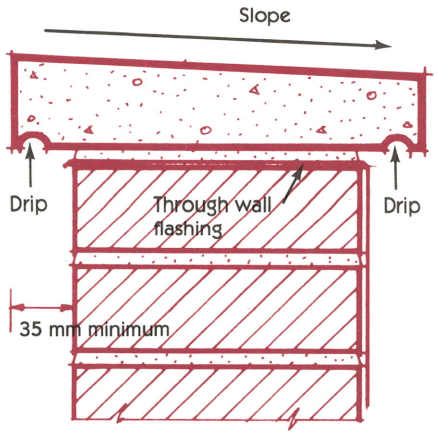


Fig. 40 Flashing below pervious or segmental coping.

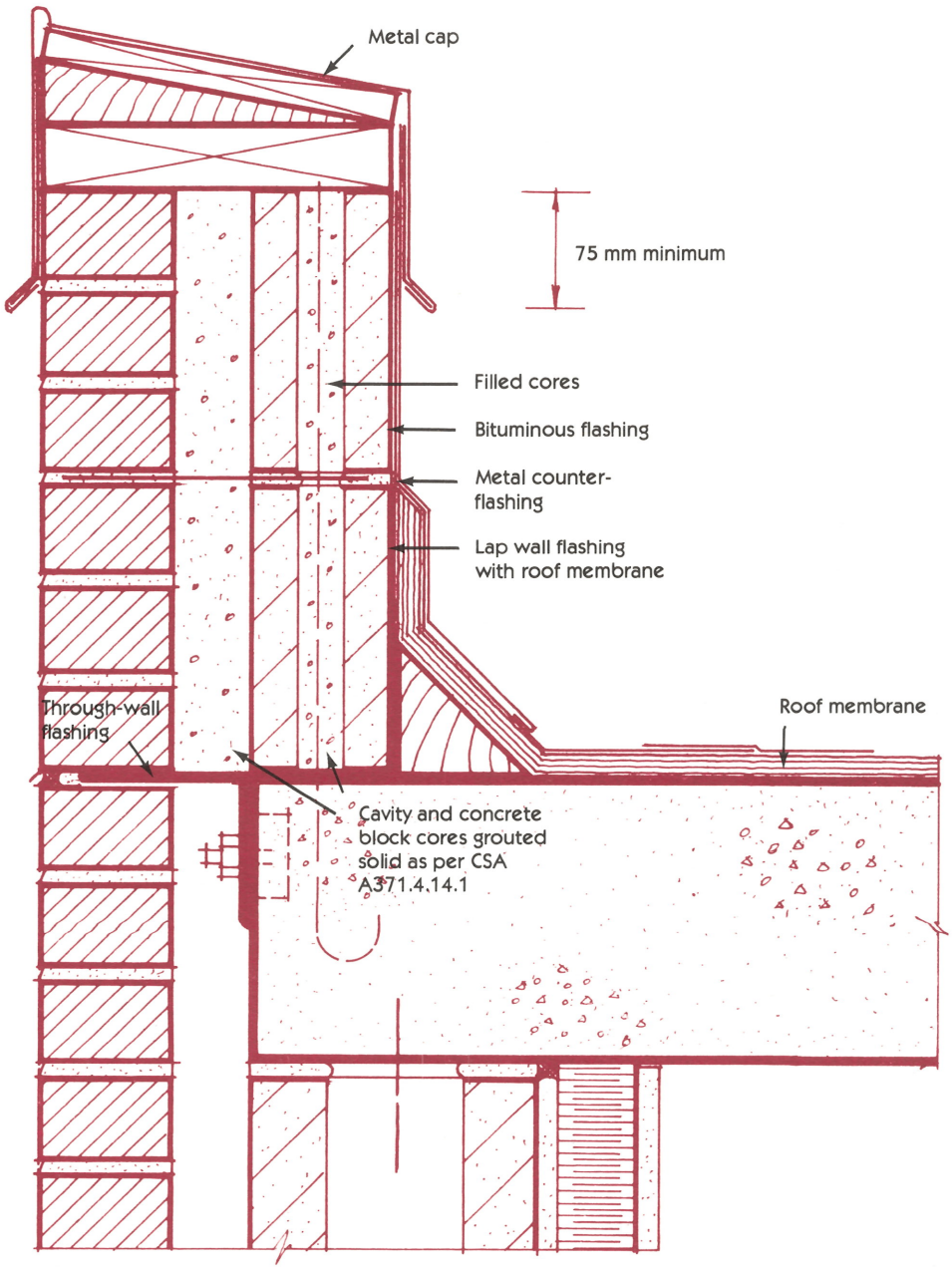


Fig. 41 Parapet flashing

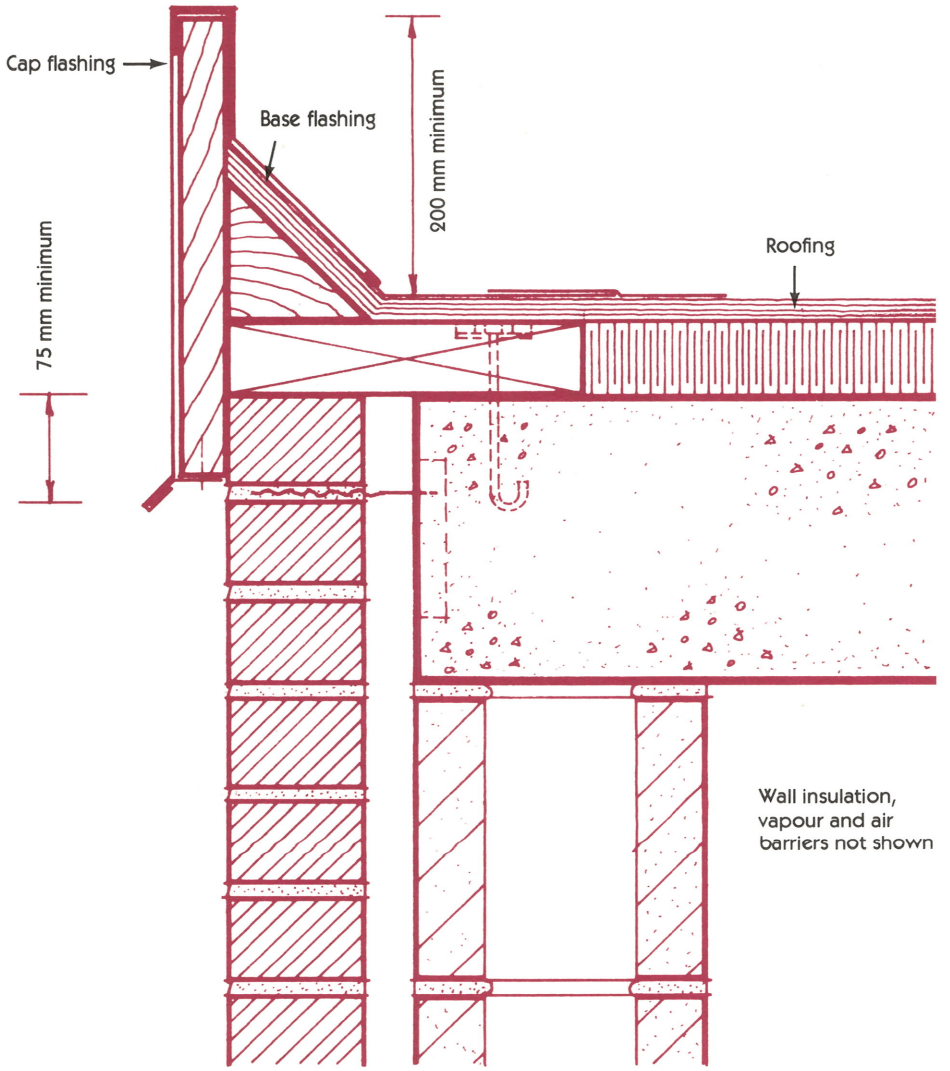


Fig. 42 Flashed curb

6.3 Weepholes

Cavity flashings should be sloped towards the outer wythe but will not drain unless there are openings in the brickwork through which accumulated water can drain. Small openings, called "weepholes," must therefore be left in the brickwork just above the flashings. These are best formed by omitting the mortar in vertical joints at about 600 mm centres. Smaller holes of about 70 mm^2 are permitted by codes. These may be formed by metal rods, which are removed after laying the units, or by small tubes left in place, but they are difficult to keep clear of debris. Permeable fibrous wicks, such as sash cord, have been used, but are prohibited by CSA A371 since they become filled with salts and dirt and are relatively ineffective.

Weepholes are prone to become plugged with bits of mortar dropped into the cavity during bricklaying (Fig. 43). Various measures can be used to prevent this, a commonly suggested one being to place a narrow strip of wood in the cavity to catch the droppings, which then can be lifted out occasionally by withdrawing the strips by wires connected to them. An alternative is to leave holes at the bottom of each cavity to be cleaned out at the end of every day. Rope laid at the base of the cavity and raised after the droppings have partially hardened have been used to loosen them and to prevent them from being a solid mass at the weepholes. If the masons take reasonable care, and bevel the mortar bed towards the cavity, this will minimize droppings and help alleviate the problem.

When weepholes are plugged or not provided for by the design, it is common at certain times of the year to observe a line of damp masonry at each floor level.

Weephole deficiencies:

- weepholes not provided
- weepholes too far apart
- weepholes too small
- weepholes plugged.

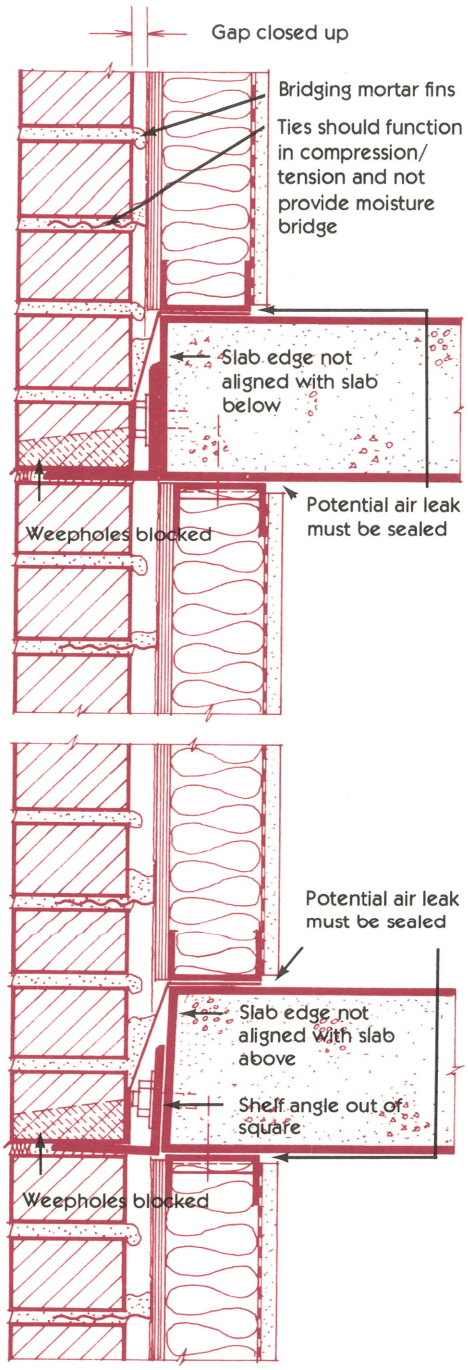

Gap closed up
Bridging mortar fins
Ties should function in compression/ tension and not provide moisture bridge
Slab edge not aligned with slab below
Potential air leak must be sealed
Weepholes blocked
Potential air leak must be sealed
Slab edge not aligned with slab above
Shelf angle out of square
Weepholes blocked

Fig. 43 Plugged weepholes and misaligned slab edges (Ref. 16)

6.4 Cavity Obstructed or Bridged by Insulation

Rigid insulation placed in cavities should be tightly and securely fastened to the inner wythe, leaving at least a 25 mm clear space between it and the outer wythe. Insulation should not be loosely placed in a cavity. Not only will it be thermally ineffective because of the air circulating around it, but it may also form a water bridge across the cavity, as at 'A' in Fig. 39. Foamed plastic spacers may help to hold the insulation tight to the inner wythe if the adhesive fails.

6.5 Exterior Drainage

- All exterior horizontal surfaces should, as far as possible, be designed so that rain or melting snow does not drain onto the brickwork
- Balconies should not be made level or drain towards the wall but should have a positive slope towards drains at the outward edge
- Caps and coping should slope towards the roof
- Wind will blow water up and under a parapet cap that does not overlap the masonry sufficiently. About a 75 mm overlap is recommended (Fig. 41)
- Copings, sills and other ledges should project beyond the exterior face of the masonry and be provided with drips, to prevent water running inward along the underside of the projection (Figs. 40, 41, 44)
- Stone, concrete, or metal sills should have upstands at the ends to prevent water from flowing laterally onto the wall (Fig. 44).

6.6 Joint Tooling

For reasons previously discussed, all mortar joints should be tooled to a concave or V-profile. Raked joints should not be used in exterior walls.

6.7 Misaligned Slab Edges

The edges of floor slabs and shelf angles in successive storeys should line up within about 6 mm. The mason can "make up" perhaps 10 mm, but cases have been reported where the misalignment was 25 mm or more. As is shown in Fig. 43, this can lead to a narrowing of the cavity, making placement of flashings difficult. If there is insulation in the cavity, it may be squeezed against the outer wythe, making it nearly impossible to install, as well as plugging the weepholes.

If the misalignment is in the opposite direction, the brickwork may not be properly seated. The bottom course of a brick facing should not project more than 30 mm beyond the edge of the shelf angle (CSA S304 Clause 3.4.2), or a minimum bearing of two-thirds of the brick width (CSA A371, Clause 4.10.2). In some cases, bearing of as little as 38 mm has been found (Ref. 32).

Problems of misalignment can be partially prevented by using a cavity of ample width to allow for misalignment and shelf angles with adjustable connections instead of fixed angles.

6.8 Missing Ties

Too frequently in buildings, ties are carelessly placed, unevenly spaced, or missing altogether. In some cases, whole panels have been left untied and are precariously held up by the adjacent construction. This is due in part to the lack of clear indication of the type, size and spacing on drawings.

6.9 Inoperative Movement Joints

Joints provided for masonry expansion have sometimes been filled inadvertently with mortar. This should be checked before the joint sealant is applied.

6.10 Shelf Angles

To perform their function of supporting the outer wythe of a cavity or veneered wall, shelf angles must be stiff and anchored to the slab or frame, as specified by the designer. There should not be discontinuities in the shelf angles, even around short returns. Thermal expansion gaps, normally about 6 mm, should, however, be left between the abutting ends of adjacent lengths of angle (Fig. 37).

Cases have been found where the bolts connecting angles to slabs or beams had not been properly tightened to the designer's specifications. It is very expensive to break into the wall to tighten them but it has had to be done. In extreme cases, inadequate connections, such as ordinary spikes, have been found.

CHAPTER 7. SPECIAL TOPICS

7.1 Window and Door Frame Connections

Most of the facade of high-rise residential buildings is made up of windows. They are exposed to the weather as much as the wall and their performance requirements are even more rigorous. While admitting light and ventilation, they must be structurally adequate, resistant to water and air infiltration and exfiltration, control heat flow and sound, and be warm enough on the inside surfaces to avoid condensation. Appearance, durability, ease of installation and cleaning are also factors that must be taken into account in their design. Some manufacturers now employ modern technology to cope with thermal losses and surface temperatures, and "rain screen" principles for water and air resistance. With windows designed for various climates and different building uses, the number of available sash and frame profiles is practically unlimited. For this reason, an adequate discussion of the design and selection of windows would require a treatment beyond the scope of this publication. However, introduction to the principles of window performance may be found in References 33 to 35.

Probably because of the wide variety of walls into which windows are placed, most publications on windows give meagre treatment, if any, to the joint or transition between the window frame and the walls. More attention should be paid to this, however, since the window-wall intersection can be a source of rain leakage, air leakage, dampness, and durability problems.

Figure 44 shows several important features of a window installation. If the window head looks into a cavity, it is obvious that there must be a flashing over it to keep water getting through the outer wythe away from the top of the window. This flashing should be sloped to direct water away from the inner wythe and should extend 150 or 200 mm on either side of the frame with upturned ends. Weepholes to the outside are also required.

Whether of metal, stone, or precast concrete, the sill should project beyond the face of the brickwork and should have a drip. Inadequate details here cause brick deterioration, dampness, and staining or efflorescence from rain and melting snow. Frequently, the run-off water concentrates at the corners and flows laterally onto the brickwork, so that sills should have upstands at the ends to confine the water. Water permeable segmental sills must have flashings below them since the joints between the segments will eventually leak.

The outside joint between the frame and the brick reveal is most frequently caulked against rain with a sealant bead. This sealant should adhere tightly and retain some flexibility after curing to accommodate small differential movements between the window and the wall. The sealant must also be durable under air, water, freezing and sunlight. Poor quality sealants can cause rain leakage and must therefore be maintained frequently.

Not always so obvious is the need for a seal at the inside of the frame. Although the inside surface of the window glass, sash, and frame combination may be air-tight, with an effective air barrier also provided in the wall, there is a discontinuity at the frame-wall junction. Under inward or outward pressure caused by stack effect, mechanical ventilation, or wind, air will flow through the joint if it is not sealed. If the flow is outward, moisture is carried into the wall and causes dampness around windows. Moisture carried through to the outer wythe and condensing there is frequently noticeable as dampness and/or efflorescence at window jambs and below sills, especially if a higher than normal relative humidity is maintained inside. Inward flow of air will cause cold inside wall surfaces around windows, which can also lead to condensation, dampness and mildew.

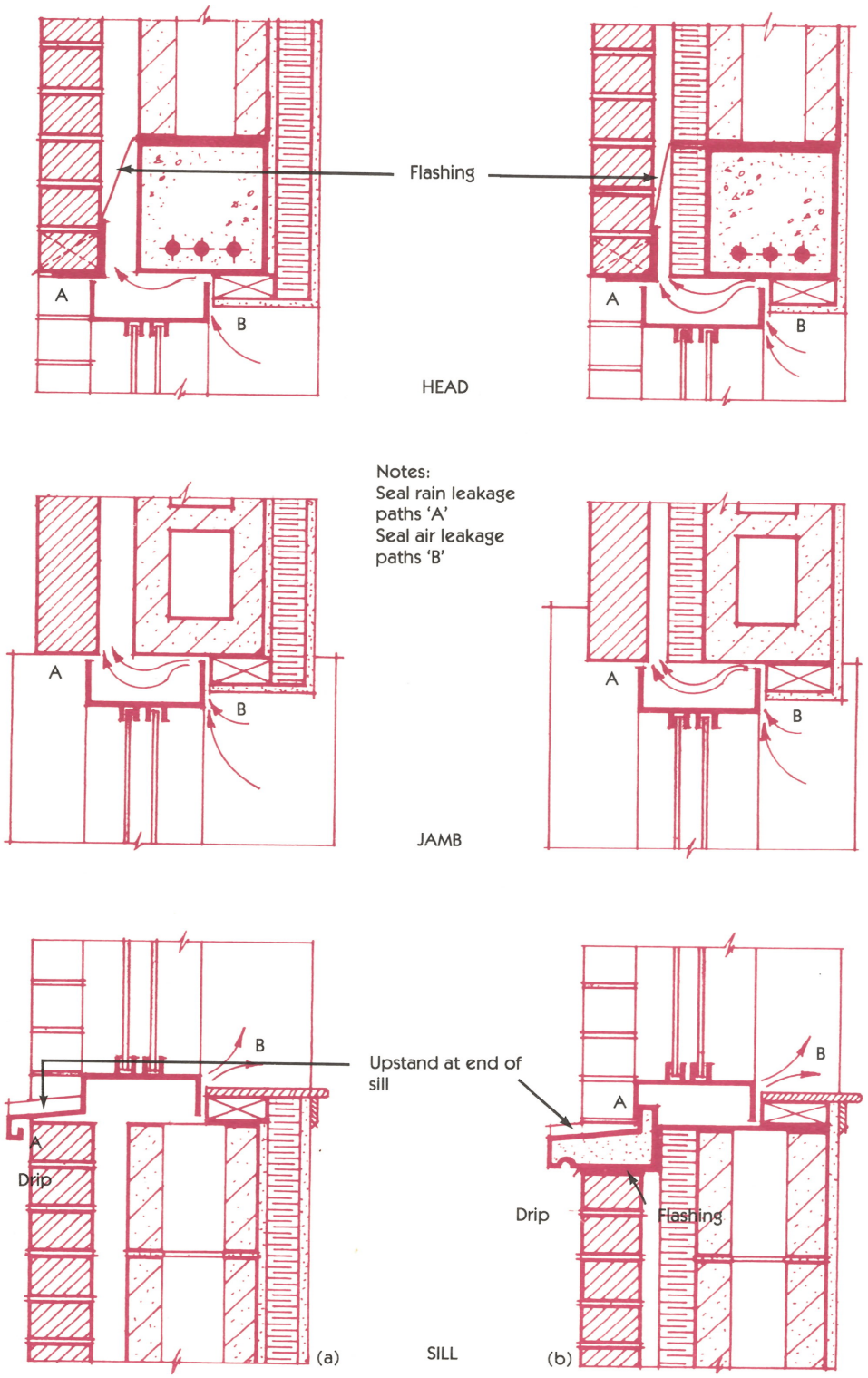


Fig. 44 Air leakage at window to wall connection

Figure 45 shows schematically the general problem which must be solved for each window-wall combination. As is shown in Fig. 45(a), loosely fitting inside finishes are not effective barriers to air. A positive seal, such as a strip of membrane material sealed to the wall air barrier and the window, is needed (Fig. 45(b)) to block air passages through cracks and cores in brick or block. The actual details will depend on the configuration of the window-wall assemblage around the perimeter of the frame.

Doors also have their own special designs and functions which are not covered here, but the foregoing discussion applies in general to the connection of door frames as well.

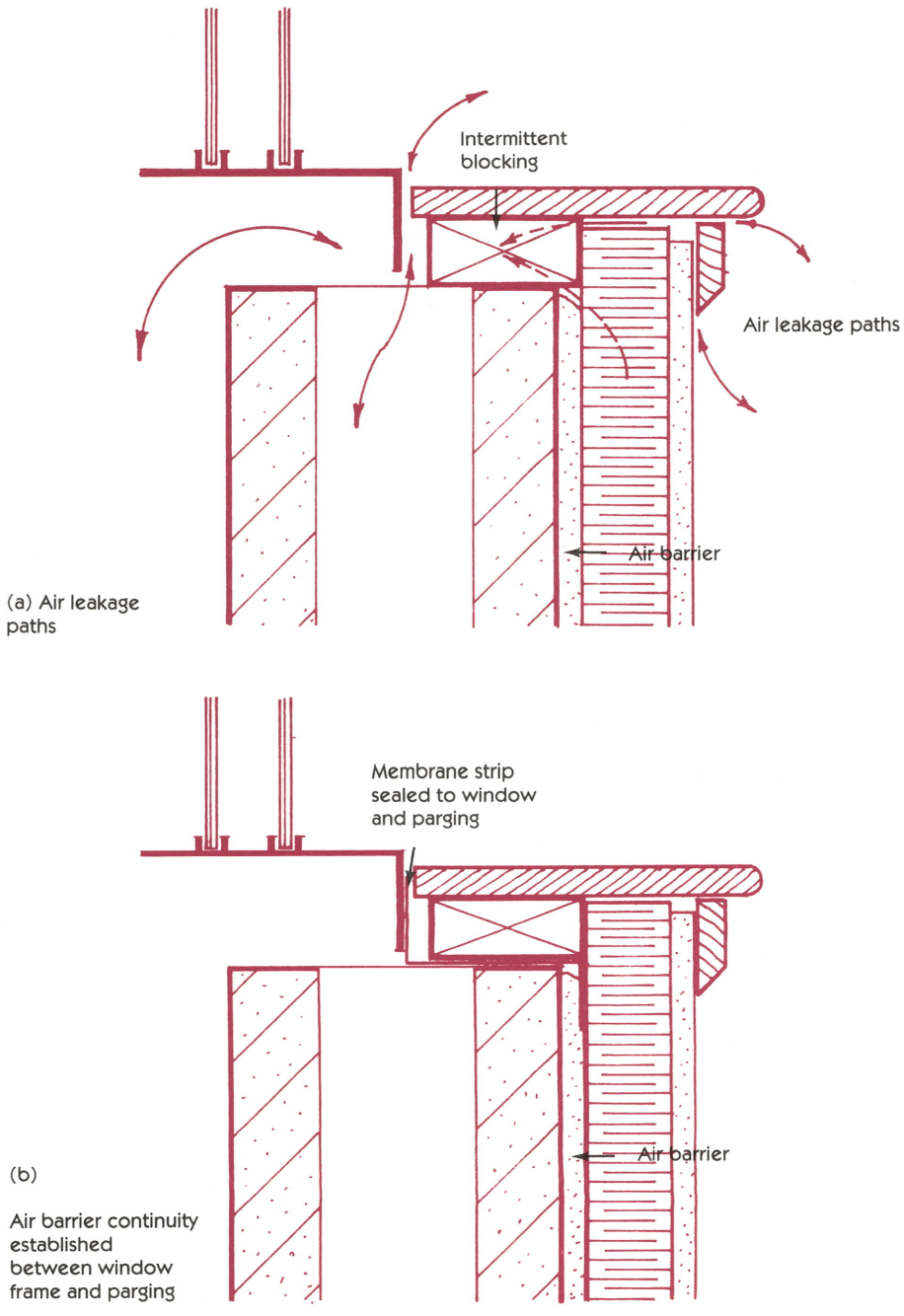


Fig. 45 Air leakage at sill

7.2 Sealants

Standards and Selection

In exterior walls, sealants are required to caulk expansion/contraction joints and intersections between panels or components of dissimilar materials, such as brickwork, metal panels and windows. Their main function is to exclude rain, snow and dirt from the joints and, in some cases, to prevent air leakage. Their value for these purposes depends on their ability to adhere tightly to surfaces and, through flexibility, to permit movements in joints without rupture and loss of sealing capacity. They must also retain these characteristics at low temperatures and for long periods of time. Sag resistance, drying time, extrudability, stain resistance, storage life, self-levelling capacity, sensitivity to moisture conditions, and traffic resistance are other properties to be considered in the choice of sealants.

To ensure a degree of predictability and reliability of sealing compounds, NBC Part 9 requires that they conform to one of the following CGSB Standards:

19-GP-3 Sealing Compound, Two Component, Polysulphide Base, Chemical Curing

19-GP-5 Sealing Compounds, One Component, Acrylic Base, Solvent Curing

19-GP-9 Sealing Compound, One Component, Silicone Base, Chemical Curing

19-GP-14 Sealing Compound, One Component, Butyl-Polyisobutylene Base, Solvent Curing

19-GP-15 Sealing Compound, Multicomponent, Polyurethane Base, Chemical Curing

Standard specifications ensure that for stated uses the workability and physical properties of sealants are tested with standard equipment under standard conditions and are judged uniformly. To perform as expected, in general sealants must be applied within the correct temperature range on dry and clean surfaces in conformance with the manufacturer's instructions.

Sealants of the right extensibility and adhesion must be selected for the particular joint design and the movements to be allowed for. With the wide variety of products available and the many kinds of field conditions, it is stated in the foreword to the standards that "it remains the responsibility for the user of the standard to judge its suitability for his particular purpose." CGSB Standard 19-GP-23, *Guide to the Selection of Sealants on a Use Basis*, offers some assistance in this, but good experience with a given sealant under similar conditions of service is the best guide.

An important thing to remember is that brickwork is a porous material. Where it is frequently wet, moisture can be absorbed behind the adhesion surface, weakening the bond; therefore, sealants suitable for this condition should be used.

Two-component polysulphide-based sealants are known to have a good record in such situations.

Joint Shape

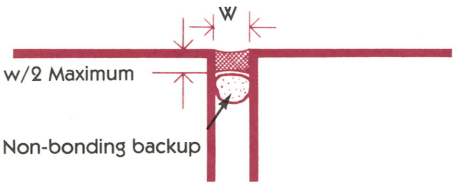
The design of sealant joints is discussed in detail in several readily available publications. To summarize briefly, the shape of the sealant bead has a considerable effect on its durability and performance. Sealing compound simply smeared over a crack is sure to fail because of the exposure of the material and the high concentration of stress at the crack (Figs. 46a, 47).

The bead shape giving the least stress on the adhesion surface and within the material itself is one that is concave on both sides (Fig. 46b). The curvature on the inner side is usually obtained by inserting a compressible plastic rope material, for example closed-cell polyethylene foam, that will not adhere to the sealant. The backup also serves to control the depth and uniformity of the bead cross-section. For proper application of a high-performance, ±25% movement capacity sealant, the joint should be a minimum of 6 mm wide and the depth of the sealant should be not more than about half the width of the joint. However, more depth is recommended for low movement capability sealants (Ref. 36).

Joints having a square or rectangular backing (Fig. 46c) are often used where expected movements are small or where the slot is too shallow for a rope backup, but where possible it is best to place a bond-breaking tape at the base of the joint.

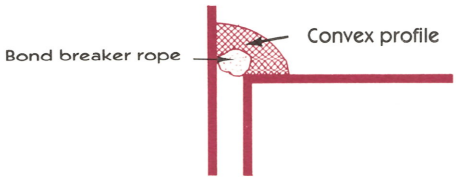
Fillet beads of uncontrolled shape are sometimes used where little or no movement is expected. Fillets required to undergo significant movement should have a convex profile and a bond-break in the corner to eliminate concentration of stress (Fig. 46d).

A) Unsatisfactory seal

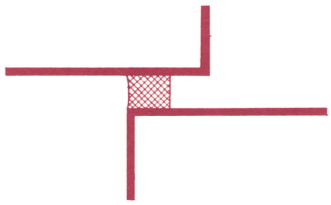


B) Best sealant shape for tension/compression

C) Rectangular joint



D) Fillet of controlled shape



E) Lap joint for shear movement

Fig. 46 Sealant shapes and Bond Breakers

Fig. 47 An example of a poorly applied sealing compound

7.3 Freeze-Thaw Durability

Common Joints

In brick cavity and veneered facades, the major locations requiring sealants are at expansion joints, below shelf angles or slabs, and around doors and windows.

In vertical joints designed to permit horizontal movements due to temperature and moisture effects, the movement capacity required of the sealant depends on the design width and the spacing of the joints. With a 12 m spacing of expansion joints, for example, the width of the joint will seldom be less than 25 mm and the expected movement will be in the order of 6 mm. Therefore, elastic sealants (usually described as "rubber-like solids") having at least a ±25% movement capacity are required for such joints.

Movement gaps below shelf angles (Fig. 32), or below slabs where exposed slabs are used (Fig. 8), can be expected to close up about 50 per cent. The net movement in the joint will always be in the compression direction and the sealant will not be as prone to rupture or leakage failure as in the case of alternating tension and compression. Sealants of lower elastic movement capability (±5 to 10 per cent) can accommodate the large movement through slow permanent deformation. At this location, an initial concave profile helps to minimize protrusion of the sealant from the joint.

Between window and door frames and brickwork, movements will normally be small, but because of the potential for leakage and the difficulty of maintenance in high buildings, there is a need for good adhesion and durability, and only best quality sealants should be used in high-rise construction.

One of the best features of masonry is its long-term durability. Its general resistance to a harsh environment is clearly evident everywhere. Nevertheless, cases of masonry breaking down because of freeze-thaw action do occur; these are disfiguring and expensive to repair. In some instances, authorities have issued unsafe notices because of falling fragments.

Freeze-thaw resistance is not a definite property of a porous material as compared to, say, strength or colour. For example, whether or not a brick fails during freeze-thaw depends on the pore structure, the rate of freezing and the thickness of material, and it must be saturated to near the limit of its absorption capacity. Standard criteria, such as strength, absorption and absorption coefficient, are known to be rather unreliable predictors, accepting as many as 20 per cent of bricks that will fail the freeze-thaw test and rejecting about 30 per cent of resistant ones. Hard-fired bricks usually are relatively durable, but even a small difference in firing temperature, in the order of 50°C, can cause a change in freeze-thaw resistance from good to bad, or vice-versa.

CSA Standard A82.1-1977 permits acceptance of brick if the average saturation coefficient is less than 0.88, or the average compressive strength is less than 8000 psi, or if the 24-hour cold water absorption is less than 8 per cent. At best, these criteria are "fairly accurate measures" of the resistance of bricks to freeze-thaw tests. At variance with the standards, CMHC Builders' Bulletin No. 310 (Ref. 41) does not permit waiver of the 0.88 saturation coefficient, even though the last two requirements are satisfied. Compliance with all three criteria is intended to give greater assurance of durable bricks and has been found necessary because of freeze-thaw problems where the strength and cold water absorption satisfied the standard.

The freeze-thaw test (CSA A82.2-M78) is a more reliable predictor, but it simply shows that a brick wetted to a certain degree of saturation and frozen at a certain rate for an arbitrary number of cycles will fail or not fail.

In situ effects are not simulated. A brick that disintegrates or cracks at a low number of test cycles is, however, suspect for locations where the brickwork is likely to become saturated. Unfortunately, freeze-thaw tests require up to three months to perform, which discourages their use.

7.4 Efflorescence

The most reliable test of all is actual exposure to the environment for several years on several buildings. One authority from a company making approximately one-quarter of the bricks in the USA suggests that five years service is necessary to give good assurance that the brick is durable (Ref. 38). Unless the service record of the brick is well-known, the freeze-thaw resistance requirements of CSA A82.2-M78 should be observed. While not infallible, they are almost certain to reveal a brick that has very low freeze-thaw resistance.

Above all, it is necessary to remember that it requires a high degree of saturation to cause damage. Lack of weepholes, faulty flashings, incorrect drainage slopes, and excessive air exfiltration can cause such conditions. Figure 48 shows brick damage by frost action where water from balconies drained onto the brickwork. The bricks in this case had moderate to low resistance under the freeze-thaw tests, but were performing satisfactorily where they were not subjected to this treatment.

Fig. 48 Brick damage from frost action

Salts, usually white sodium and potassium sulphates, leached out of units and mortar and deposited on the surface of masonry, are called efflorescence. When it occurs, it is disfiguring, annoying to owners, and a sign of moisture.

The source of the salts may be the mortar, or the units, or both. Increasing cement content in the mortar generally increases efflorescence, but a given mortar showing pronounced efflorescence with one brick may not with another, and it is related as well, therefore, to the absorption rate of the units.

Often efflorescence appears on newly constructed masonry during the initial drying-out period, but in a season or so it disappears. When it persists from year to year, a source of wetness should be looked for, since without moisture, efflorescence can hardly occur. Poor drainage, splashing, wicking and severe exposure to rain can be causes, and a great deal of otherwise unaccountable efflorescence is actually caused by moisture deposited in masonry by air leakage and carried to the surface by capillary action.

Efflorescence is likely to be most pronounced in cool weather. At such times evaporation is slow and takes place right at the surface of the masonry where the salts carried by the evaporating moisture are deposited. In warmer temperatures, evaporation takes place below the surface and the salts are not visible; salts deposited earlier are usually washed away by rain or carried back into the masonry. References 39 and 40 are concise and informative treatments of the subject and also discuss appropriate test methods for predicting the efflorescing tendencies of the materials.

7.5 Thermal Bridges

Where a column, cross-wall, floor slab, stud, or other element of low thermal resistance penetrates a wall past the insulation, it forms a heat path or "thermal bridge" (Fig. 49). This causes the building to lose heat and, because of the local reductions of indoor surface temperatures, can cause condensation or, in some instances, dust marking at the zones of lower temperature.

The effects of thermal bridges vary widely, depending on the relative thermal conductivities of the materials and their configuration in the wall. Theoretical treatments are possible for some simple cases (Refs. 42-45) but the most useable information is based on testing. Much of this work has been done in Europe and only approximately represents Canadian construction. Nevertheless, the information in Reference 44 indicates that heat loss through thermal bridges can increase the overall heat loss from a wall by 25-50 per cent. Thermal bridges are, therefore, not inconsequential. The higher figure would apply approximately to a slab projecting through a masonry wall having R12 insulation (Fig. 49). Other test results reported in Ref. 11 indicate that at an outside temperature of −18°C, the temperatures at 'a' and 'b' could be reduced to about 6°C, in which case there would be a danger of condensation locally at these points, especially in corners, at relative humidities above 35 per cent. Whether or not condensation actually occurs depends as well on factors such as air movements and the use of carpets.

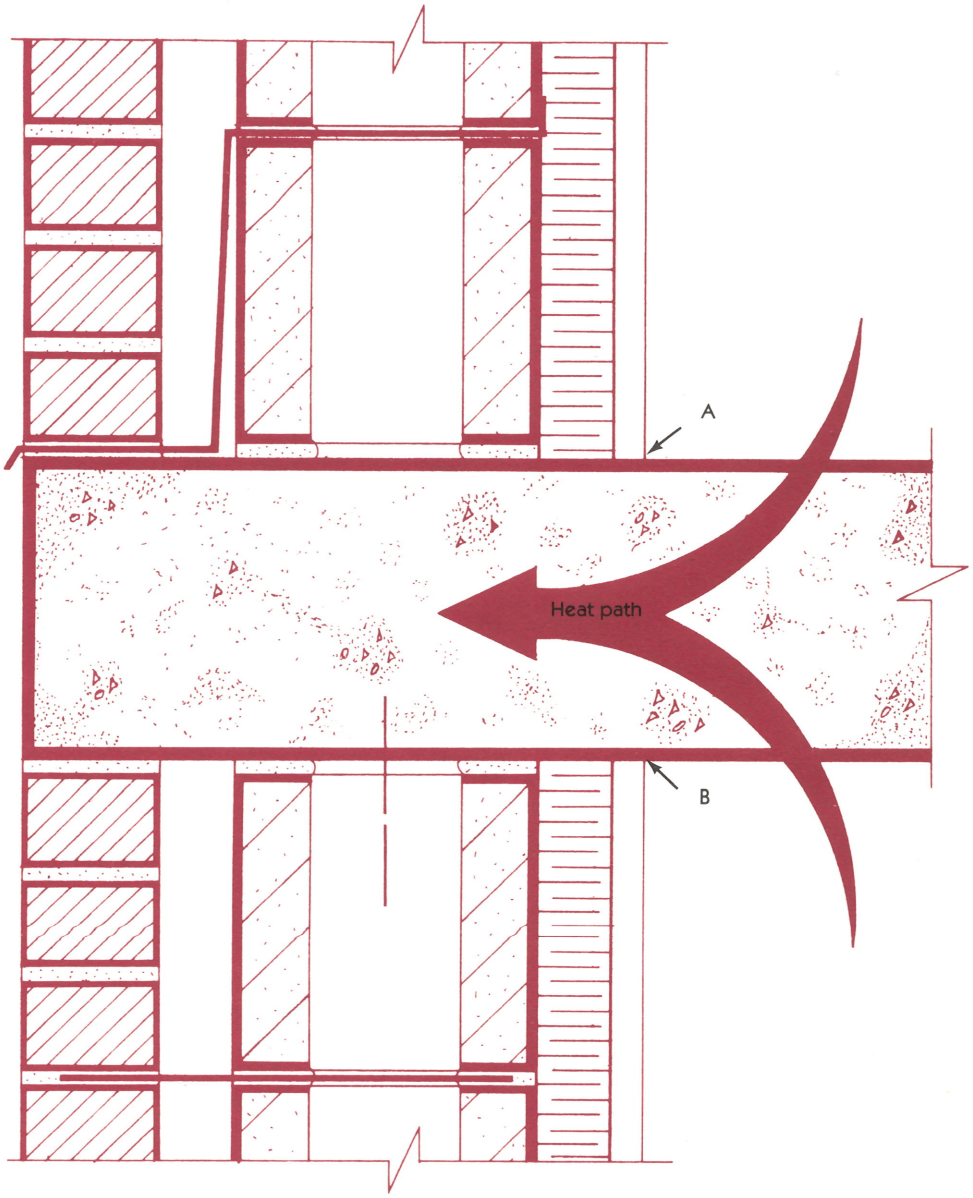


Fig. 49 Thermal bridge at floor slab

7.6 Anchorage

Thermal bridges cannot be eliminated in practical construction. Their effect can be reduced, however, by suitable use of insulation and other materials according to simple intuitive strategies that are discussed in Ref. 11. One such strategy mentioned earlier is to put insulation in the cavity of a cavity wall. This then enables the insulation to be continuous over the inner wythe and the floor slab.

In the case of steel stud walls, CMHC Builders' Bulletin No. 332 requires 25 per cent of the total wall insulation to be applied over the studs on one side or the other. This is to reduce the thermal bridge effect of the studs, thus improving their heat resistance, and to raise the inside wall surface temperature over the studs to reduce dust marking.

The anchorage of walls to columns, beams and cross-walls has been mentioned previously and is indicated in the sketches. It is logical that, if a wall is designed to receive support from another building element, it must be connected to it (CSA S304, Clause 3.6). The design of connections is the designer's responsibility and may involve anchorages to the vertical supports, horizontal supports, or both.

The designer may also require the joint between the top of the inner wythe and the slab or beam above to be packed with mortar (as, for example, in Fig. 6). Alternatively, depending on the slenderness of the wythe and the anticipated vertical movements of the frame, the designer may require this to be left open as a movement gap. Packing the joint with mortar does not in itself constitute anchorage. The joint may often be too narrow to pack properly and will receive simply a smear of mortar. Also, the shrinkage of a concrete block inner wythe can cause a crack to occur at this point, even if it is initially filled.

Anchorage of the inner wythe to columns and other vertical members is usually done with some type of strap anchor (CSA S304, Clause 3.6.2) (Fig. 28). The connections between the top of a wall and a horizontal supporting beam or slab require more ingenuity on the part of the designer because of the difficulty of placing the top course of the masonry. Dovetail anchors, expansion shields and bolts, and clip angles fitting into cores in the blocks are typical. In earthquake zones, the wall reinforcement is sometimes made continuous by inserting reinforcing bars through holes in the slab.

CHAPTER 8. RELATED PROBLEM AREAS

8.1 Owner Apathy

It is probably safe to say that many building-owners are not professionally trained to know whether the design of a building they are contemplating erecting will perform satisfactorily over a period of time. They tend to look at the aesthetics of the design and its cost per square metre versus its rentability. A few may enquire about the estimated costs of operating its physical plant but not about the cost of maintenance of the structure itself. This latter item is extremely important because all structures require regular maintenance, but some more than others because of their design and the cladding material used. The owner places his trust in the designer and constructor, and the reliability of these two parties can greatly influence the final cost of successfully operating the building. They should, therefore, exercise care in the selection of both the designer and the superintendent, both of whom should have demonstrated their skill and knowledge on previous projects.

8.2 Poor Design

Much of the material for this publication was based on a review of plans for buildings constructed across Canada. It was obvious from the number of errors that many designers were not aware of, or ignored, the basic principles of wall and roof design. To illustrate the point, many indicated flashing by means of a straight line on the drawings, or by a note, without giving any detail. This may have been because the designer did not know the requirements or did not think it necessary on the plan. In any event, the result may well have been inadequate or missing flashing and leaking walls. To avoid this situation, the designer must ensure that a completely detailed description by specification and/or drawing exists for:

i) Flashing
ii) Weepholes for Cavity Walls
iii) Mortar
iv) Brick and Block
v) Flashing Detail
vi) Metal Shelf Angles and Installation
vii) Masonry Metal Ties
viii) Flexible Anchorage
ix) Crack Control

8.3 Inadequate Site Supervision

On most projects, prime contractors provide little supervision of the masonry work. It is well known that superintendents often check only the rate of production and trade coordination. As a consequence, full mortar beds and joints are rare, crack control is neglected, and construction methods and materials are left to the discretion of the subcontractor. To improve on this situation, the building-owner should institute a full-time inspection service from the beginning to the end of the masonry installation. This person should preferably be from an independent inspection or testing agency. The agencies should be provided with clear terms of reference and will provide written and regular reports.

For those who do not have access to a continuing inspection service, Chapter 9, "Inspection on a Continuing Basis," may be helpful.

8.4 Poor Work Practices

There are many reasons for poor work practices, the principal one being that the interests of the workmen and sub-trades differ from those of the owner – one is maximum production, the other is quality and good performance. To upgrade the quality of the work, construction details and techniques should be made available in illustrated form and in the language spoken by the worker. These should be carefully reviewed with the sub-trades before work begins. In larger projects, a section of wall could be set up on site. This module is often used by architects to confirm the brick selection and mortar colour. It could include many of the important features discussed in this publication.

CHAPTER 9. INSPECTION ON A CONTINUING BASIS

This publication has presented an analysis of selected topics where problems frequently arise in construction of masonry cavity walls and veneers on high-rise buildings. The whole art and science of wall construction is too vast to be encompassed by one document, as is evidenced by the technical literature provided by the clay brick and concrete block industries and building research organizations.

Building codes and standards are a partial and condensed version of technology, particularly regarding those items where consensus is necessary or that are important enough to be mandatory requirements. In addition to their primary regulatory functions, they serve as a checklist to good construction. However, they are not all-inclusive nor a guarantee. Many items concerning the size and shape of the building, details and materials, are left to the discretion of the designer and owner. Nevertheless, errors and omissions can invalidate good concepts, and continuing efforts are required at all stages of design and construction.

The following is a summary of the points discussed as a checklist for reference. *It is assumed that in all other respects the materials, design, and construction are in accordance with standards and good practice.*

Design and Inspection for Serviceability

Item	Discussion Page	Governing Code or Standard	Action Required in: Design Detailing and Specification Stage	Action Required in: Approvals Stage	Action Required in: Construction Stage
General Items					
Structural Design:					
• By a professional engineer or architect	21	NBC-1980 (4.1.1.2)	x	x	x
Materials:					
• Wall materials in accordance with codes and standards		NBC-1980 (4.4) (5.5.1) Res. Stds.-1980 (IA) CMHC Builders' Bulletins CSA A371* CSA S304* and appropriate other standards referenced therein.	x	x	x
Construction:					
• Wall constructed in accordance with codes and standards		Ditto	x	x	x

*At present both CSA A371 and S304 must be referred to for masonry materials and construction requirements. In the near future, it is expected that this overlap will be eliminated.

Item	Discussion Page	Governing Code or Standard	Action Required in: Design Detailing and Specification Stage	Approvals Stage	Construction Stage
Specific Serviceability Items Discussed in This Publication					
Structural:					
• Cavity Wall Ties					
Type	4	CSA S304 (3.7.3) CSA A371 (4.6.3 - 4.6.4)	x	x	x
Size	4	CSA S304 (3.7.3)	x	x	x
Spacing	5,12	CSA S304 (3.7.3)	x	x	x
Installation	12,40 51	CSA S304 (3.7.3) CSA 371 (4.6.3, 4.6.4, 4.4.1, 4.17.6, 4.17.4)	x	x	x
• Veneer Ties		NBC-1980 (5.5, 5.6) CSA S304 (6.1.2)			
Type	9	CSA S304 (6.2.6)	x	x	x
Size	9	Ditto	x	x	x
Spacing	12	Ditto	x	x	x
Installation	12 40 51	CSA S304 (6.1.3, 3.1.16) CSA A371 (4.17.6, 4.17.14)	x	x	x
Corrosion resistance	12	CSA A371 (3.33.1)			
Connection to metal studs	12	CSA S304 (6.1.2)	x	x	x
• Anchors		NBC-1980 (5.5, 5.6)			
Type	60	CSA S304 (3.6)	x	x	x

Item	Discussion Page	Governing Code or Standard	Action Required in: Design Detailing and Specification Stage	Approvals Stage	Construction Stage
Size	60	CSA S304 (3.6)	x	x	x
Spacing	60	CSA S304 (3.6)	x	x	x
Installation	60	CSA A371 (4.11, 4.17.14)	x	x	x
• Shelf Angles		NBC-1980 (5.6)			
Connectors					
Size	51		x	x	x
Spacing	51				
Bolt Tightening	51		x	x	x
Continuity	51		x	x	x
Expansion Gaps	51		x	x	x
Alignment of angles for proper bearing	50	CSA S304 (3.4.2) CSA A371 (4.10.2)	x	x	x
• Water (Rain) Resistance					
Masonry					
Mortar in accordance with standards	14,15	CSA S304 (3.3.2) CSA A371 CSA A179	x	x	x
Units in accordance with standards	14,15	CSA S304 (3.3.1) CSA A371	x	x	x
Workmanship			x	x	x
Filled Joints	14,15				
Tooled Joints	15,50	CSA S304 (6.2.2) CSA A371 (4.7.2.2)			
Flashing					
Material	44	NBC-1980 (5.5, 5.6) CSA A371 (3.5.2)	x	x	x

Design and Inspection for Serviceability

Item	Discussion Page	Governing Code or Standard	Action Required in: Design Detailing and Specification Stage	Approvals Stage	Construction Stage
Location	42	CSA S304 (3.16) CSA A371 (4.13.3)	x	x	x
Continuity and Laps	44	CSA S304 (3.16.2) CSA A371 (4.13.3)	x	x	x
Details — at discontinuous ends	44	CSA S304 (3.16.2) CSA A371 (4.13.3)	x	x	x
— at columns and intersections	44	CSA S304 (3.16.2) CSA A371 (4.13.3)	x	x	x
— provision of reglets where necessary	44	CSA A371 (4.13.3.9)	x	x	x
Prevention of damage	44		x		x
• Weepholes					
Type and size	49	CSA S304 (3.13) CSA A371 (4.13.1)	x	x	x
Location	49	CSA S304 (3.13) CSA A371 (4.13.1)	x	x	x
Prevention of Plugging	49	CSA A371 (4.13.1.4, 4.17.13)	x	x	x
• Slope and drips					
Sills	50		x	x	x
Ledges	50		x	x	x
Balconies	50		x	x	x

Item	Discussion Page	Governing Code or Standard	Action Required in: Design Detailing and Specification Stage	Approvals Stage	Construction Stage
• Parapets					
Design and construction	98	NBC-1980 (5.3.5) CSA A371 (4.14.1)	x	x	x
Slope of cap	50		x	x	x
Flashing	46	NBC-1980 (5.3.5) CSA A371 (4.14.1)	x	x	x
Cap	110	NBC-1980 (5.3.5) CSA A371 (4.14.1.2)	x	x	x
Overlap of metal caps	50		x	x	x
Thermal Resistance:					
• Material		NBC-1980 CSA A371 (3.5.4, 4.13.4)	x	x	x
• Overhall thermal resistance in accordance with standards	17 22	CMHC Builders' Bulletins #282 and 332	x	x	x
Uniformity of insulation	22 59	CSA A371 (4.13.4.1)	x	x	x
Fasteners and adhesives for insulation	29,49	NBC-1980 (5.5, 5.6) CSA A371 (4.13.4.3)	x	x	x
Vapour Resistance:					
• Provision of identifiable planes of major vapour resistance (vapour barrier)	17,18, 23,26, 43	NBC-1980 (9.26.5.1, 9.26.5.2)	x	x	
• Vapour barrier to be in accordance with standards	22,43	NBC-1980 (5.2.1, 5.5.1, 5.6.1, 9.26.3.4, 9.26.5) CSA A371 (3.5.3, 4.13.5)	x	x	x
• Continuity of vapour barrier	23	NBC-1980 (9.26.5) CSA A371 (4.13.5.2)	x	x	x

Design and Inspection for Serviceability

Item	Discussion Page	Governing Code or Standard	Action Required in: Design Detailing and Specification Stage	Approvals Stage	Construction Stage
Air Leakage Resistance:	18,19				
• Provision of identifiable air barrier	19,24,31		x	x	x
• Air barrier to be in accordance with standards		NBC-1980 (5.2.1, 5.3.2)	x	x	x
• Continuity of air barrier					
- above drop ceilings	31		x	x	x
- at joints and intersections			x	x	x
- between air barrier and window frames	31 52		x	x	x
Movement Joints:					
• Vertical Joints for horizontal expansion control	19,20 32	NBC-1980 (5.6.1.4)	x	x	x
Location in accordance with expected movements and good practice	32,37		x	x	x
Joint width detailed and specified	35		x	x	x
Joint sealants detailed and specified	51,55		x	x	x
• Horizontal joints for vertical movements					
Movement joints at shelf angles and floor slabs detailed and specified	30,38 55		x	x	x
Durability:					
• Units - Extensive evidence of previous freeze-thaw resistance in a variety of exterior exposures	77		x	x	
OR					
- Compliance with freeze-thaw resistance tests and requirements of standards		NBC-1980 (5.5) CSA S304 (3.3.3) (3.6.2.6) CMHC Builders' Bulletin #310			
• Ties and anchors	12,60	NBC-1980 (5.5) CSA S304 (3.3.3.1)	x	x	x

APPENDIX A APPLICABLE CODES AND STANDARDS

The design and construction of high-rise buildings must conform to codes and standards as well as any additional bulletins or regulations of CMHC. The following is a guide to such standards that most directly relate to above-grade exterior walls.

1. National Building Code of Canada (1980)

Part 3 Use and Occupancy
(Clauses relating to fire)

Part 4 Design
Section 4.1 — Structural Loads and Procedures
(safety, structural design, design loads, drawings, calculations, inspection, wind)

Section 4.3 — Wood

Section 4.4 — Plain and Reinforced Masonry
(Refers to CAN 3-S304-1978, *Masonry Design and Construction for Buildings.*)

Section 4.5 — Plain, Reinforced and Prestressed Concrete

Section 4.6 — Steel

Section 4.7 — Aluminum

Part 5 — Wind, Water and Vapour Protection
(General requirements regarding vapour barriers, joints, air barriers, parapets, exterior cladding, materials fastenings)

2. Residential Standards, Canada (1980)
Section 26 - Thermal Insulation and Vapour Barriers
26 C(2) *Insulation*
CSA A101-1975, *Mineral Fibre Thermal Building Insulation*
CSA A247.1-1969, *Fibreboard Roof Insulation*
CSA A247.2-1969, *Insulating Fibreboard Sheathing*
CGSB41-GP-166 (1975), *Urethane and Isolcyanurate, Unfaced, Preformed, Rigid Cellular Thermal Insulation*
26 C(3) *Vapour Barriers*
CGSB 70-GP-1a (1970), *Vapour Barrier: Sheet, for Use in Above-Grade Building Construction,* (Type I and Type II)

3. Builders' Bulletin No. 332, *Energy Conservation Requirements,* Canada Mortgage and Housing Corporation, 1981.

Builders' Bulletin No. 282, *Thermal Resistance Values for Various Materials,* Central Mortgage and Housing Corporation, 1978.

Builders' Bulletin No. 310, *Burned Clay Brick for Exterior Above Grade Use,* Canada Mortgage and Housing Corporation, 1979.

4. CSA Standard S304-1977, CA3-S304-M78, *Masonry Design and Construction for Buildings.*

Standards referenced in CAN3-S304:

CSA Standards

CAN3-A31.M-75,
Series of Standards for Metric Dimensional Coordination in Building

A82.1-M1977,
Burned Clay Brick; (See Builders' Bulletin No. 310)

A82.2-M1978,
Methods of Sampling and Testing Brick

A82.3-M1978,
Calcium Silicate (Sand-Lime) Building Brick

A82.4-M1978,
Structural Clay Load-Bearing Wall Tile

A82.5-M1978,
Structural Clay Non-Load-Bearing Tile

A82.6-M1978,
Standard Methods for Sampling and Testing Structural Clay Tile

CAN3-A818-1978, *Hollow Clay Brick*

A82.21-M1978,*
Gypsum and Terms Relating to Gypsum Products

A82.25-1950,
Gypsum Partition Tile or Block

A82.42-1950,
Quickline for Structural Purposes

A82.43-1950,
Hydrated Lime for Masonry Purposes

A165.1-M1977,
Concrete Masonry Units

A165.2-M1977,
Concrete Brick Masonry Units

A165.3-M1977,
Prefaced Concrete Masonry Units

A179M-1976,
Mortar and Grout for Unit Masonry

080-1974,
Wood Preservation

W186-1970,
Welding of Reinforcing Bars in Reinforced Concrete Construction

ASTM — Standards
A116-73-73,
Zinc-Coated (Galvanized) Iron or Steel Farm-Field and Railroad Right-of-Way Wire Fencing

A123-73,
Zinc (Hot-Galvanized) Coatings on Products Fabricated from Rolled, Pressed, and Forged Steel Shapes, Plates, Bars, and Strip

A153-73,
Zinc Coating (Hot-Dip) on Iron and Steel Hardware

B227-70,
Hard-Drawn Copper-Clad Steel Wire

CGSB Standards
CGSB Standard 19-GP-23 *Guide to the Selection of Sealants on a Use Basis*

C97-47,
Absorption and Bulk Specific Gravity of Natural Building Stone, (Reapproved 1970)

C99-52,
Modules of Rupture of Natural Building Stone, (Reapproved 1970)

C126-71,
Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units

C170-50,
Compressive Strength of Natural Building Stone, (Reapproved 1970)

C568-67,
Dimension Limestone, (Reapproved 1970)

C615-68,
Structural Granite, (Reapproved 1972)

E72-74a,
Conducting Strength Tests of Panels for Building Construction

E447-74,
Compressive Strength of Masonry Prisms

BSI - Standard
BS1207-1961,
Hollow Glass Blocks

*Under preparation.
-American Society for Testing and Materials
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